

# **Superconducting Tunnel Junction Detector R&D for Neutrino Decay Search**

**Shin-Hong Kim,**

**at Neutrino Group Meeting (Sep 15, 2012)**

- **Introduction**
  - Neutrino Decay Search**
- **Superconducting Tunnel Junction (STJ) Detector**

# Collaboration Members

## Japan Group

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Kota Kasahara, Takuya Okudaira (University of Tsukuba) ,  
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Hirokazu Ishino, Atsuko Kibayashi, Yasuki Yuasa(Okayama University) ,  
Satoshi Mima (RIKEN),  
Takuo Yoshida, Yusuke Shimizu, Mikiya Nagashima (Fukui University) ,  
Yukihiro Kato (Kinki University) ,  
Masashi Hazumi (KEK)

## Korea Group

Soo-Bong Kim (Seoul National University)

## US Group

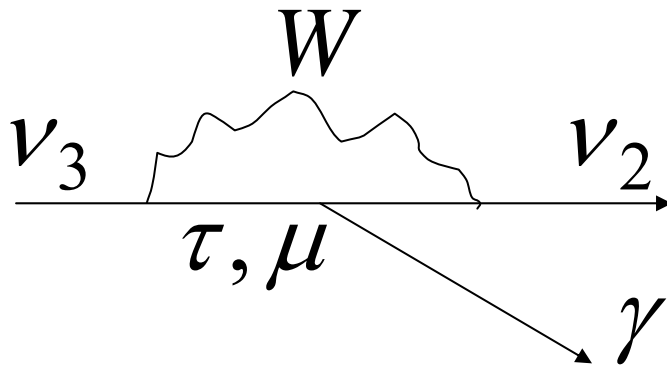
Erik Ramberg, Jonghee Yoo, Juan Estrada (Fermilab)

# Introduction

## Motivation of Search for Cosmic Background Neutrino Decay

●  $\Delta m^2_{ij}$  have been measured accurately by neutrino oscillation experiments. but **neutrino mass itself has not been measured**. Can we measure it ?

**Detection of neutrino decay** enables us to measure an independent quantity. Thus we can obtain **neutrino mass itself** from these two independent measurements.



$$E_\gamma = \frac{m_3^2 - m_2^2}{2m_3} = \frac{\Delta m_{23}^2}{2m_3}$$

Using  $\Delta m_{23}^2 = (2.43 \pm 0.13) \times 10^{-3} \text{ eV}^2$

$E_\gamma = 10 \sim 25 \text{ meV}$  at  $\nu_3$  rest frame.

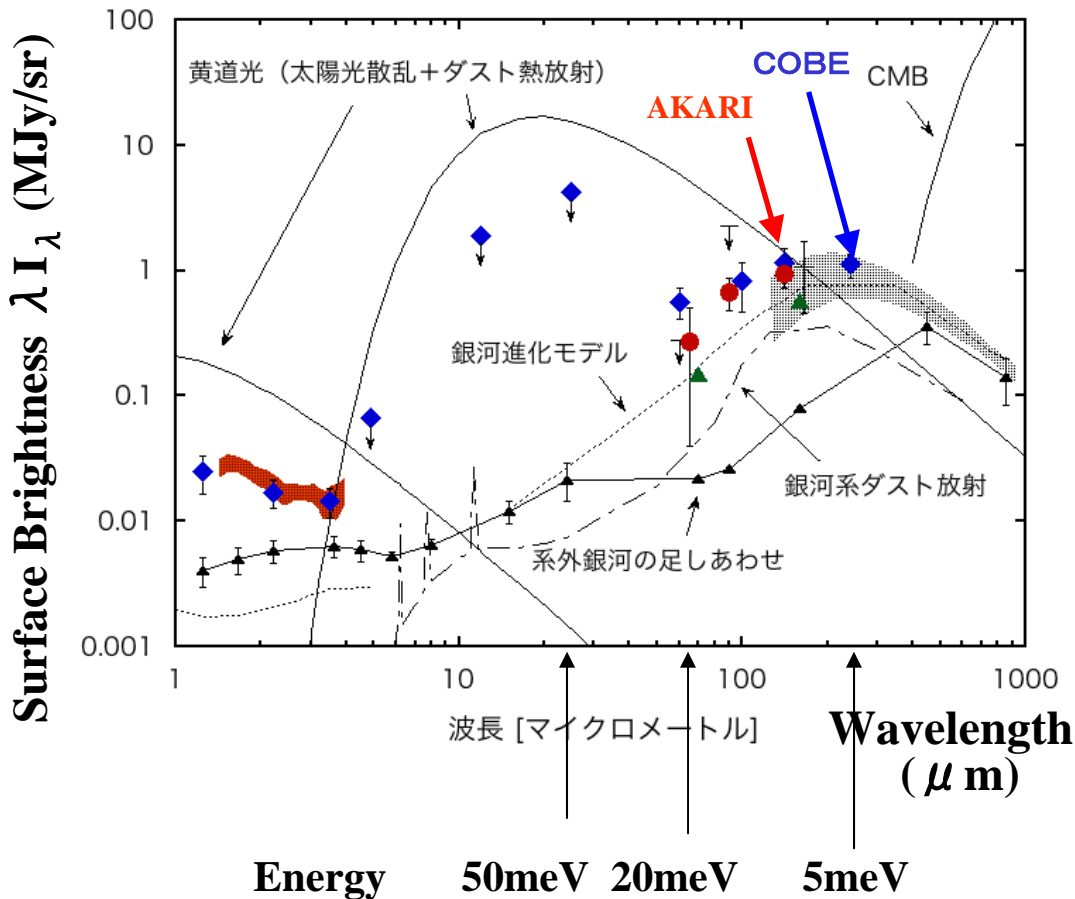
(Far - Infrared region :  $\lambda = 50 \sim 125 \mu$ )

● As the neutrino lifetime is very long, we need use cosmic background neutrino to observe the neutrino decay. To observe this decay of the cosmic background neutrino means **a discovery of the cosmic background neutrino** predicted by cosmology.

# Cosmic Infrared Background (CIB) measured by COBE and Neutrino Lifetime Limit from CIB

COBE: M. G. Hauser *et al.* *Astrophys. J.* 508 (1998) 25.  
D. P. Finkbeiner *et al.* *Astrophys. J.* 544 (2000) 81.  
AKARI: S. Matsuura *et al.* *Astrophys. J.* 737 (2011) 2.

A. Mirizzi, D. Montanino and P. Serpico,  
“Revisiting cosmological bounds on  
radiative neutrino lifetime” *PRD76*,  
053007 (2007)



CIB (Cosmic Infrared Background):  
Calculate  $\tau_{\nu}$  by the following equation:

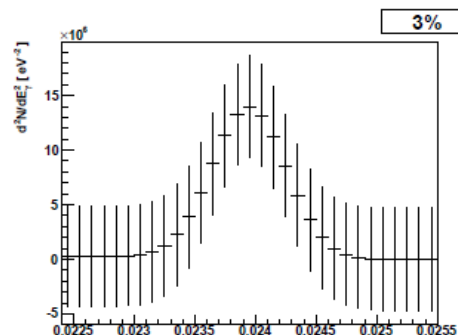
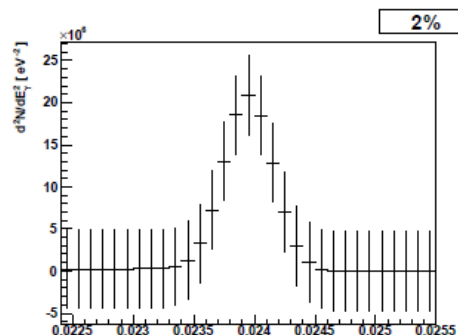
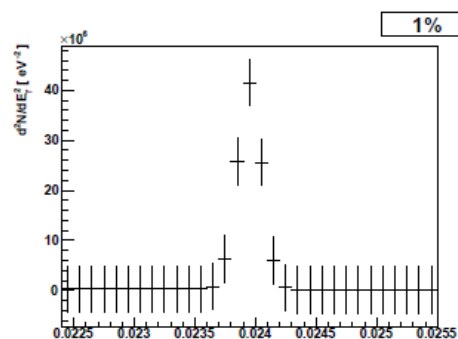
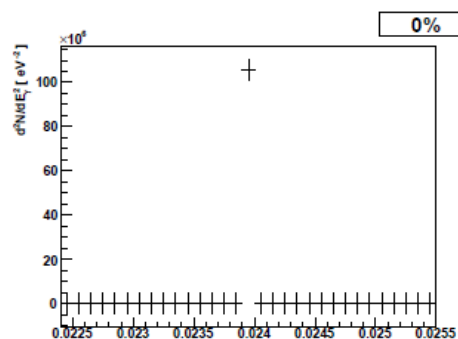
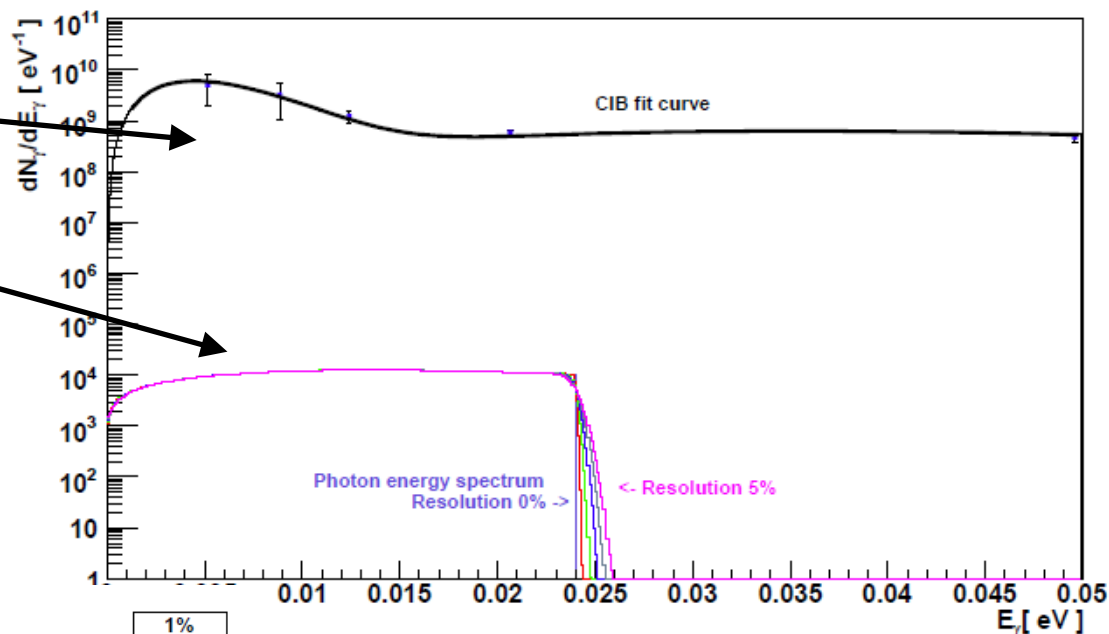
$$\int_{E_{\min}}^{E_H} \phi_E dE < \Phi_{\text{CIB}},$$

where  $\phi_{\text{CIB}} = 24 \text{ nW m}^{-2} \text{ sr}^{-1}$  (COBE).  
→  $(0.5 \sim 1) \times 10^{20} \text{ sec} = (1.6 \sim 3.1) \times 10^{12} \text{ year}$

# Neutrino Decay Detection Sensitivity

Cosmic Infrared Background +  
Photon Energy Spectrum from  
Neutrino Decay ( $E_0 = 25\text{meV}$ ,  
 $\tau = 1.5 \times 10^{17}\text{year}$   
Predicted by LR Symmetric Model)

10-hour running with a telescope  
with 20cm diameter,  
a viewing angle of 0.1 degrees and  
100% detection efficiency



$dN/dE_\gamma$

$d^2N_\gamma/dE_\gamma^2$

- Need the energy resolution better than 2%. ( plan to use STJ )
- Can observe the  $\nu_3$  decay with a mass of 50meV, and a lifetime of  $1.5 \times 10^{17}\text{year}$  at  $6.7\sigma$ .

## Search for Radiative Decays of Cosmic Background Neutrino using Cosmic Infrared Background Energy Spectrum

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<sup>1</sup>*Institute of Space and Astronautical Science, JAXA, Sagami-hara 252-5210, Japan*

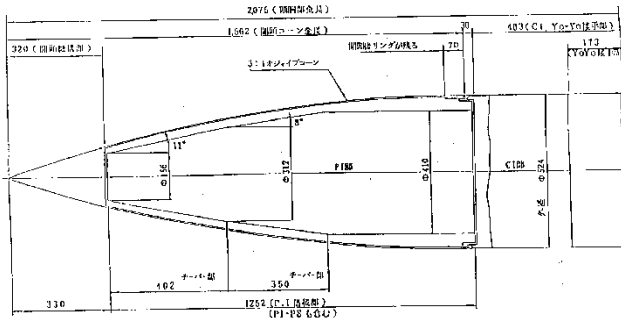
(Received September 8, 2011; revised November 22, 2011; accepted December 1, 2011; published online January 18, 2012)

We propose to search for the neutrino radiative decay by fitting a photon energy spectrum of the cosmic infrared background to a sum of the photon energy spectrum from the neutrino radiative decay and a continuum. By comparing the present cosmic infrared background energy spectrum observed by AKARI and Spitzer to the photon energy spectrum expected from neutrino radiative decay with a maximum likelihood method, we obtained a lifetime lower limit of  $3.1 \times 10^{12}$  to  $3.8 \times 10^{12}$  years at 95% confidence level for the third generation neutrino  $\nu_3$  in the  $\nu_3$  mass range between 50 and 150 meV/ $c^2$  under the present constraints by the neutrino oscillation measurements. In the left-right symmetric model, the minimum lifetime of  $\nu_3$  is predicted to be  $1.5 \times 10^{17}$  years for  $m_3$  of 50 meV/ $c^2$ . We studied the feasibility of the observation of the neutrino radiative decay with a lifetime of  $1.5 \times 10^{17}$  years, by measuring a continuous energy spectrum of the cosmic infrared background.

**KEYWORDS:** neutrino radiative decay, neutrino mass, cosmic background neutrino, cosmic infrared background, COBE, AKARI, Spitzer

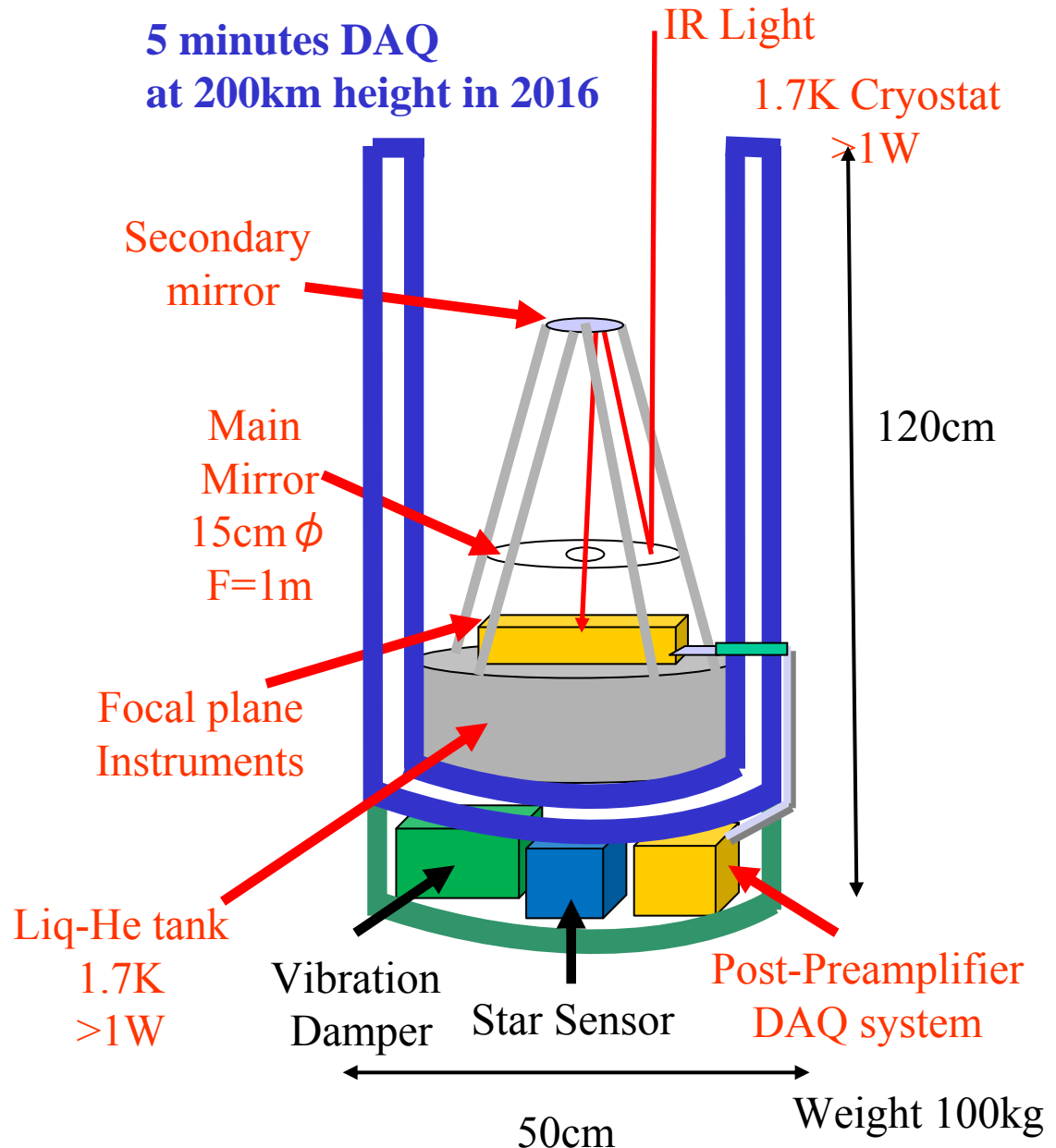
# JAXA Rocket Experiment for Neutrino Decay Search

JAXA Rocket CIB Experiment  
(Feb 2, 1992)



**Instrument weight: 42 kg**  
(maximum 100kg) ,  
**Instrument size: 1.2 m long ,**  
**52.4cm diameter.**  
**Direction control: 0.1°**

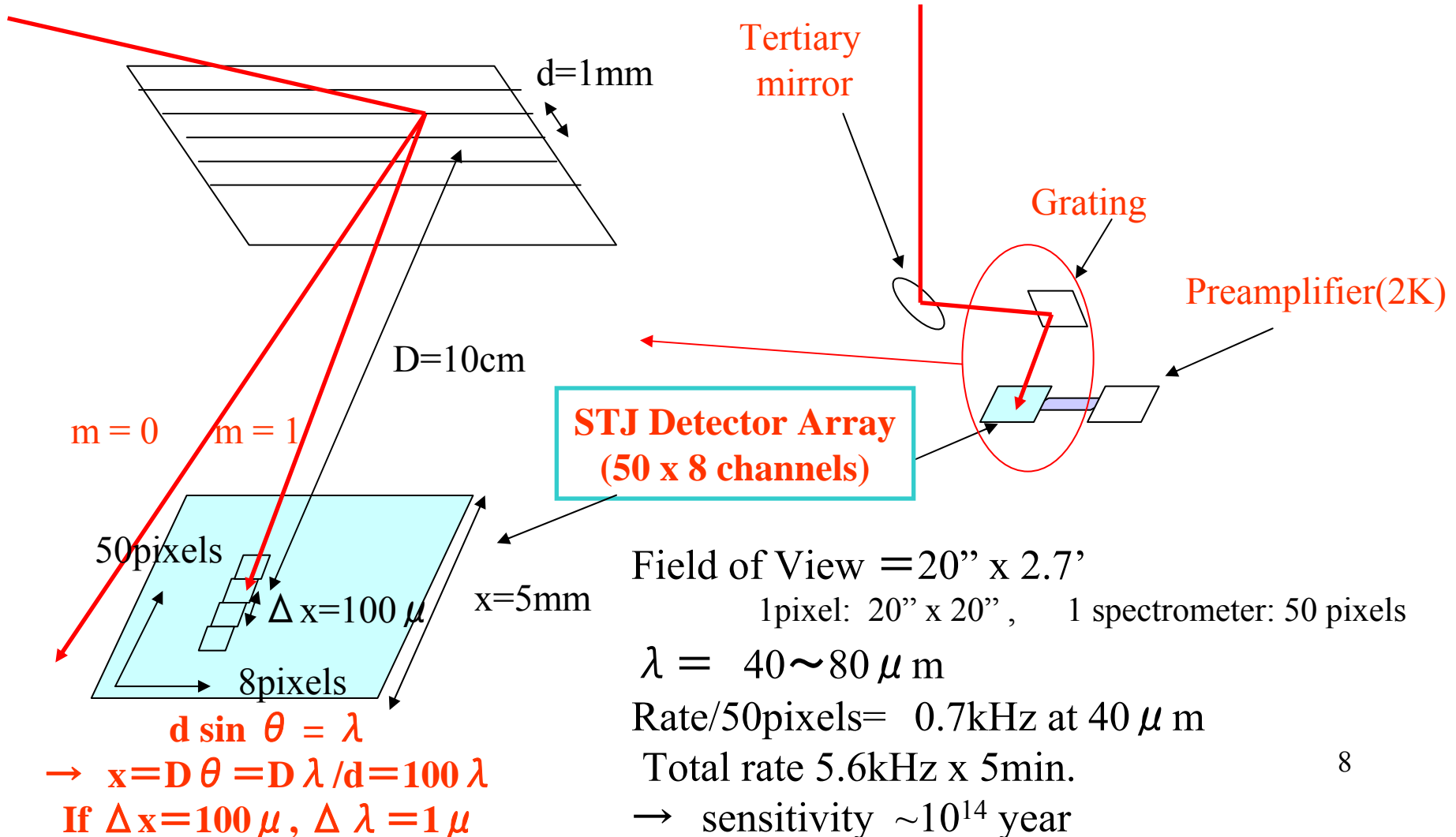
**5 minutes DAQ**  
**at 200km height in 2016**



# CIB Experiment for Neutrino Decay Search with JAXA Rocket Focal Plane Instruments

## Focal plane Instruments

Grating

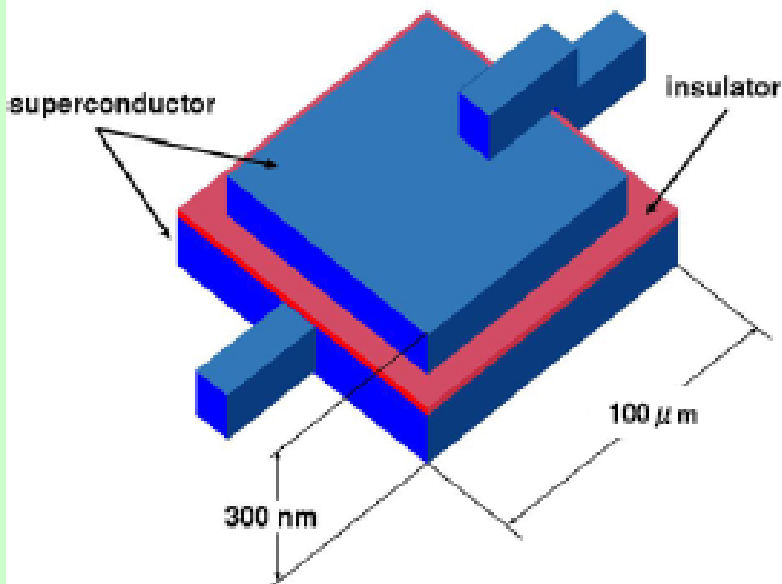




# STJ (Superconducting Tunnel Junction) Detector

- Superconductor / Insulator / Superconductor Josephson Junction

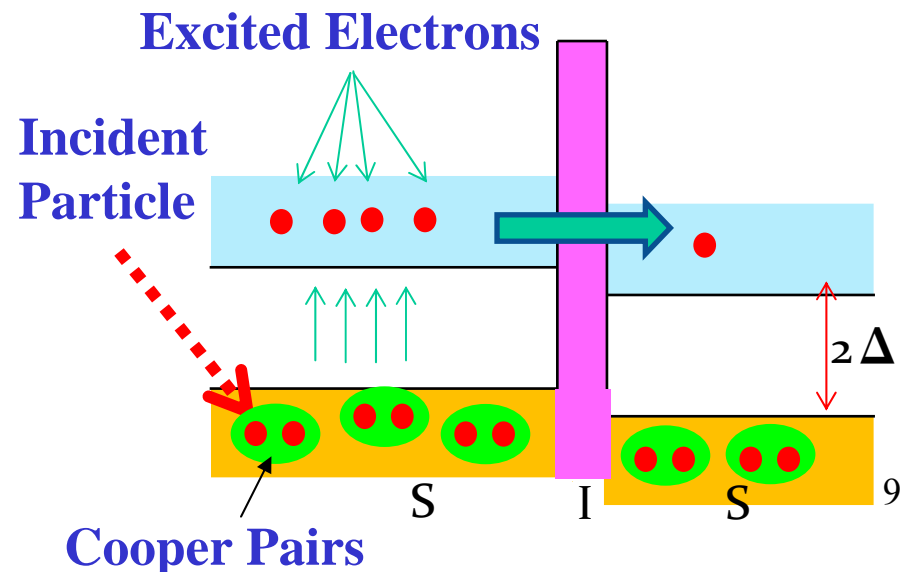
Superconducting Tunnel Junction



Material	$T_c(K)$	$\Delta(\text{meV})$
Niobium	9.20	1.550
Aluminum	1.14	0.172
Hafnium	0.13	0.021

At the superconducting junction, excited electrons (quasi-particles) over their energy gap go through tunnel barrier by a tunnel effect.

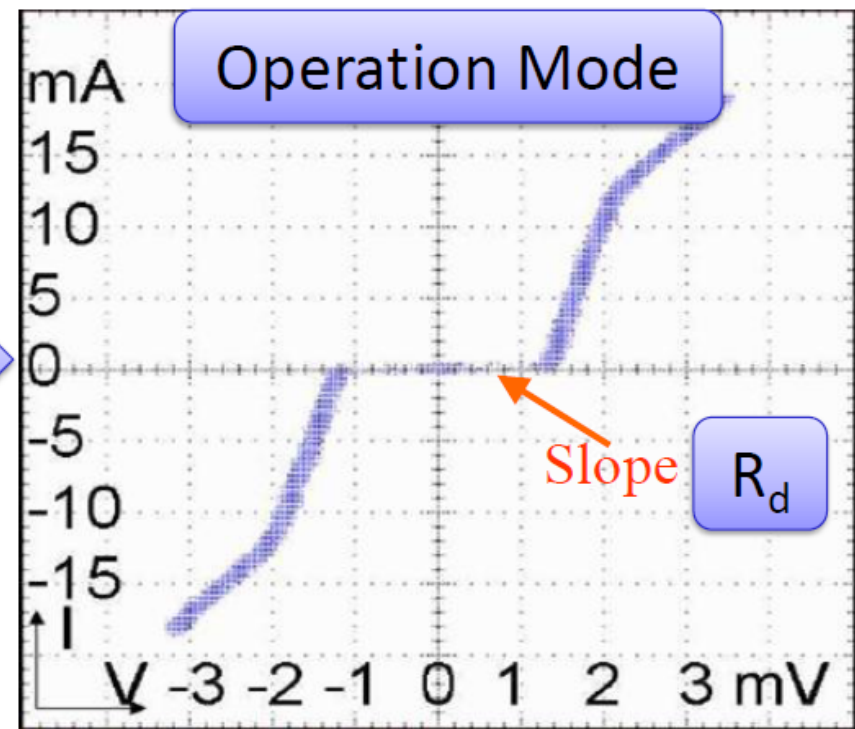
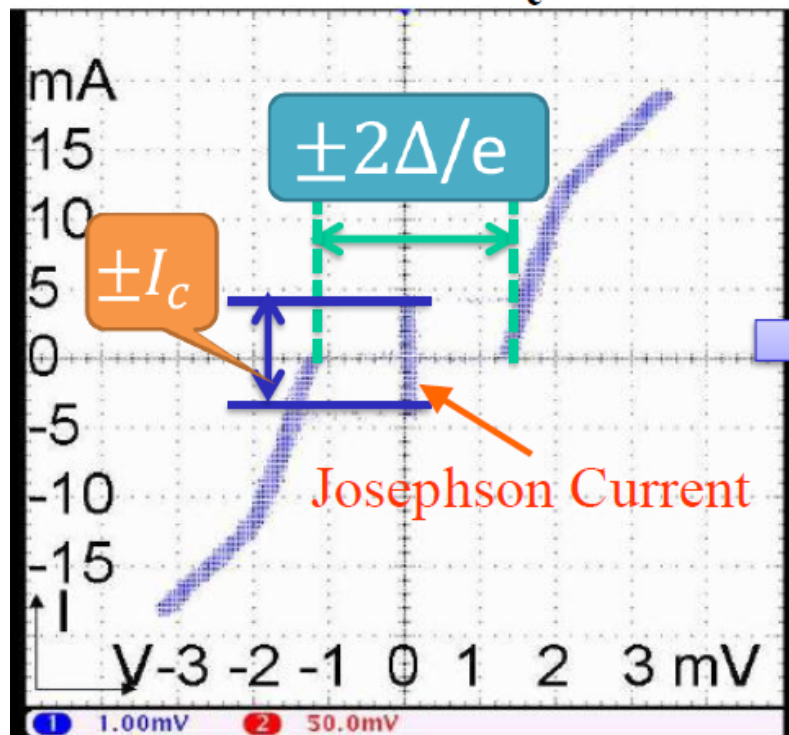
By measuring the tunnel current of electrons excited by an incident particle, we measure the energy of the particle.



# Basic Properties of STJ Detector

## Nb-STJ current -voltage (I-V) curve

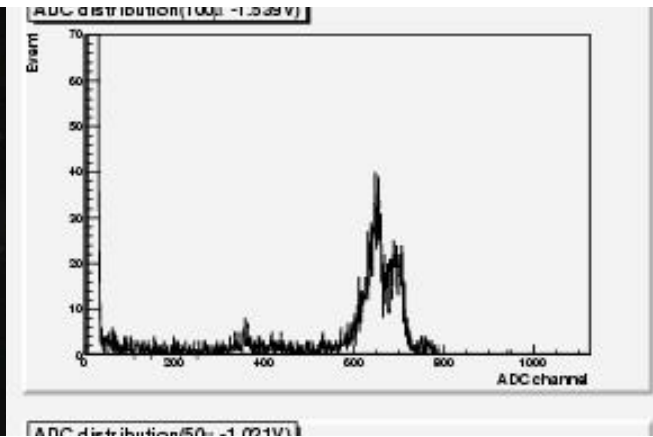
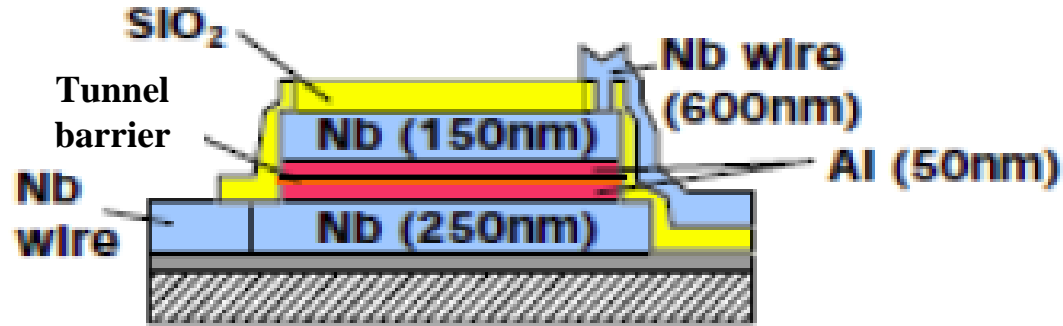
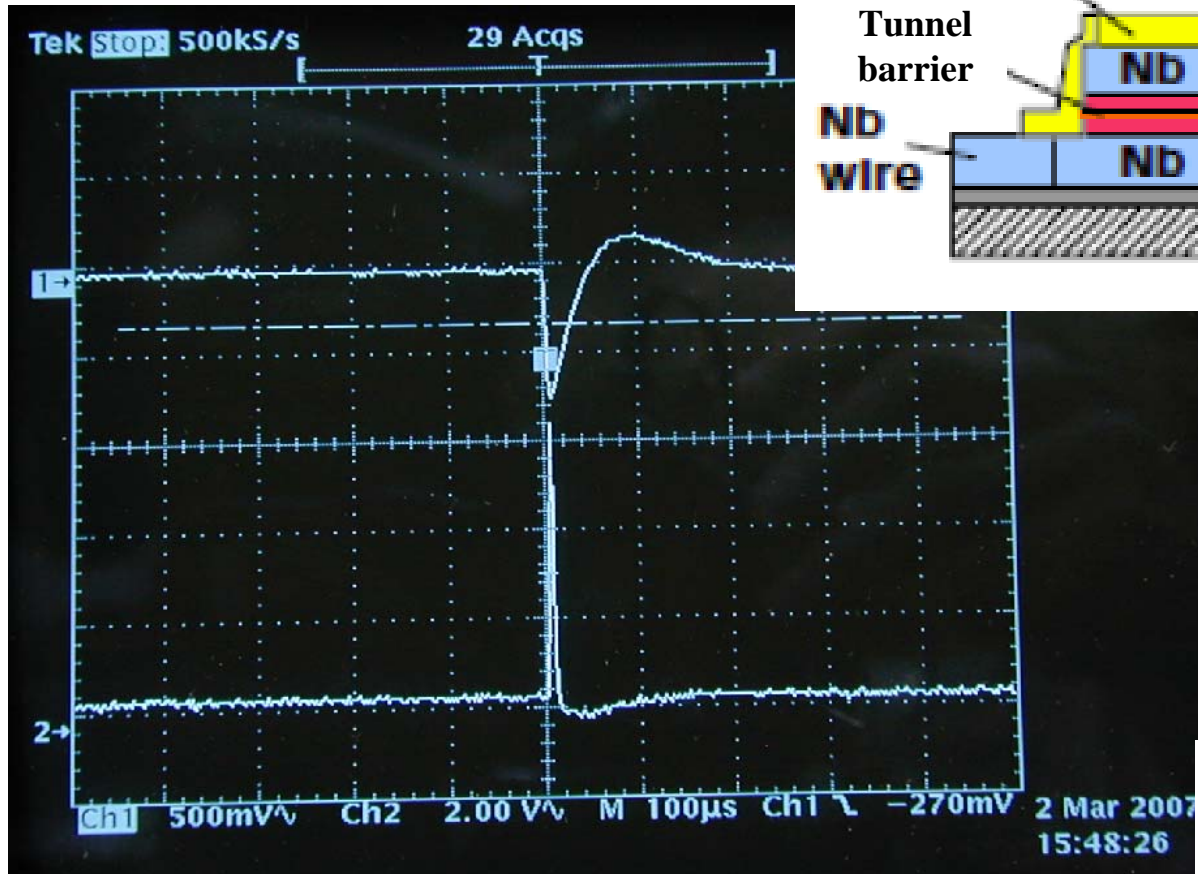
- Leakage current (Dynamic resistance  $R_d$  in  $|V| < 2\Delta/e$ )
- Energy gap  $\Delta$
- Critical current  $I_c$



Josephson Current is suppressed by a magnetic field parallel to the insulator plane

# Nb/Al - STJ Response to 5.9keV X rays

We have worked on STJ (Superconducting Tunnel Junction ) detector R&D since 2007.



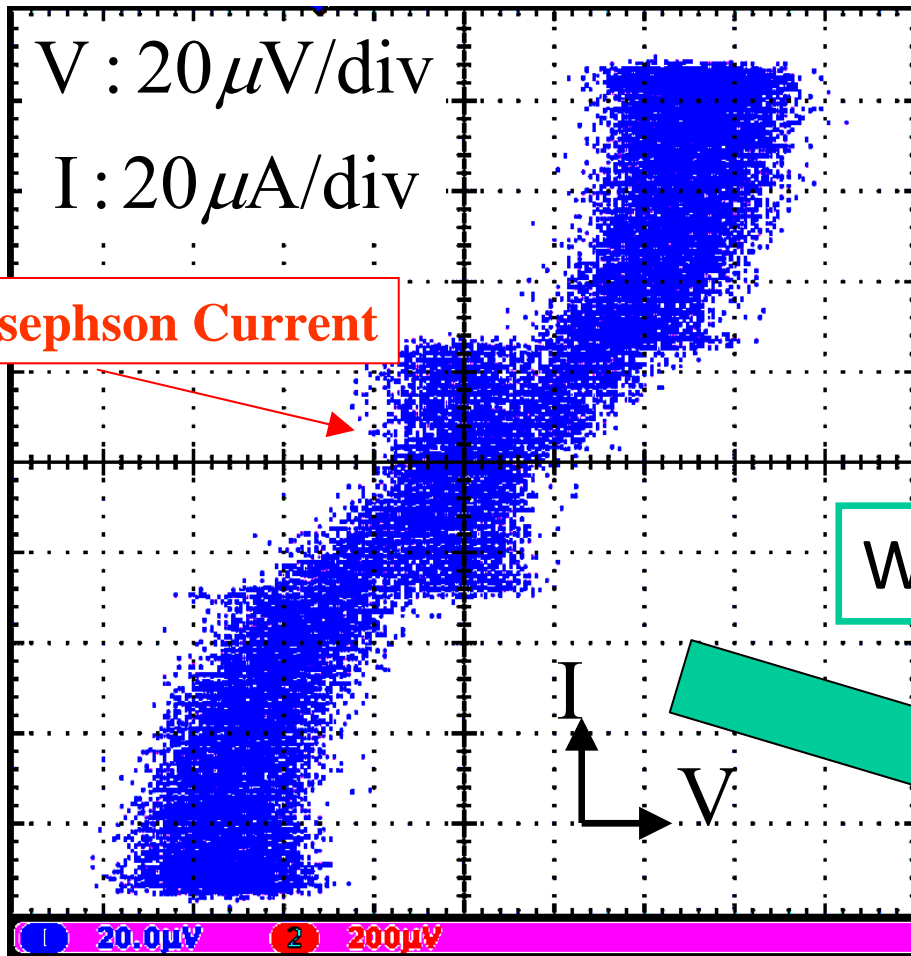
ADC output distribution

Up: 5.9keV X ray signal after preamplifier  
Down: 5.9keV X ray signal after preamp + shaper  
at T=0.4K

**Double peak comes from that X rays are absorbed both in the upper layer and the lower layer.**

# Hf-STJ I-V Curve

(Oxidation Condition: 10Torr 60min.)

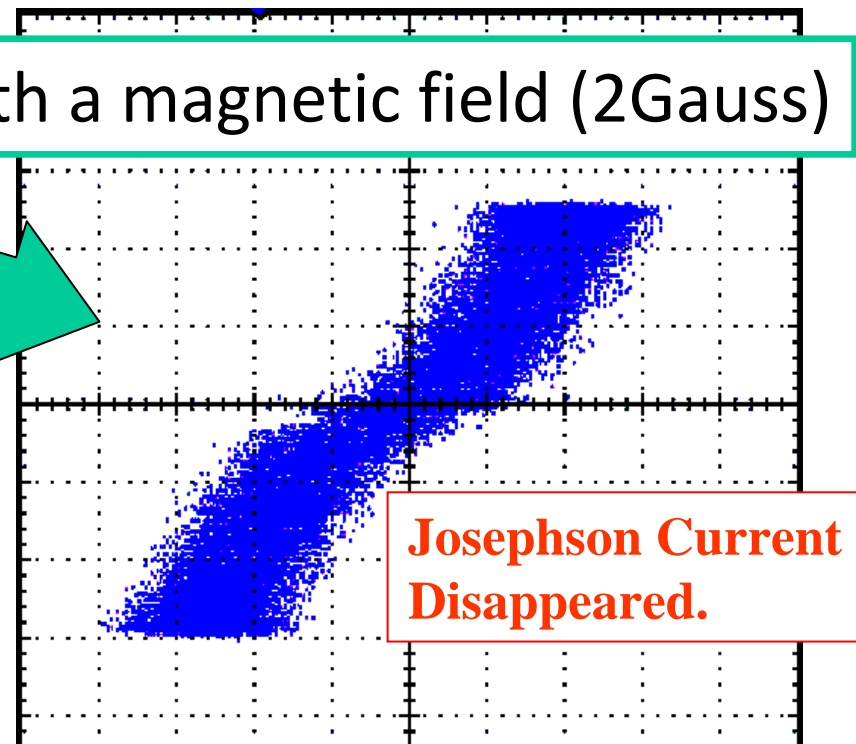


$T \sim 120 \text{ mK}$

pixel size  $200\mu\text{m} \times 200\mu\text{m}$

$I_C = 24\mu\text{A}$ ,  $R_d = 1\Omega$

With a magnetic field (2Gauss)





Available online at [www.sciencedirect.com](http://www.sciencedirect.com)



Physics Procedia 00 (2011) 000–000

Physics  
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[www.elsevier.com/locate/procedia](http://www.elsevier.com/locate/procedia)

Technology and Instrumentation in Particle Physics 2011

## Development of superconducting tunnel junction photon detector using Hafnium

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Takashi Onjo<sup>a</sup>, Ken-ichi Takemasa<sup>a</sup>, Yuji Takeuchi<sup>a</sup>, Hirokazu Ikeda<sup>b</sup>,  
Shuji Matsuura<sup>b</sup>, Hiromi Sato<sup>c</sup>, Masashi Hazumi<sup>d</sup>, Soo-Bong Kim<sup>e</sup>

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<sup>b</sup>JAXA ISAS, 3-1-1 Yoshinodai, Chuo-ku, Sagami-hara, Kanagawa, 252-5210, Japan

<sup>c</sup>RIKEN, 2-1 Hirosawa, Wako, Saitama, 351-0198, Japan

<sup>d</sup>KEK, 1-1 Oho, Tsukuba, Ibaraki, 305-0801, Japan

<sup>e</sup>Seoul National University, 1 Gwanak, Gwanak-ro, Gwanak-gu, Seoul, 151-742, Korea

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### Abstract

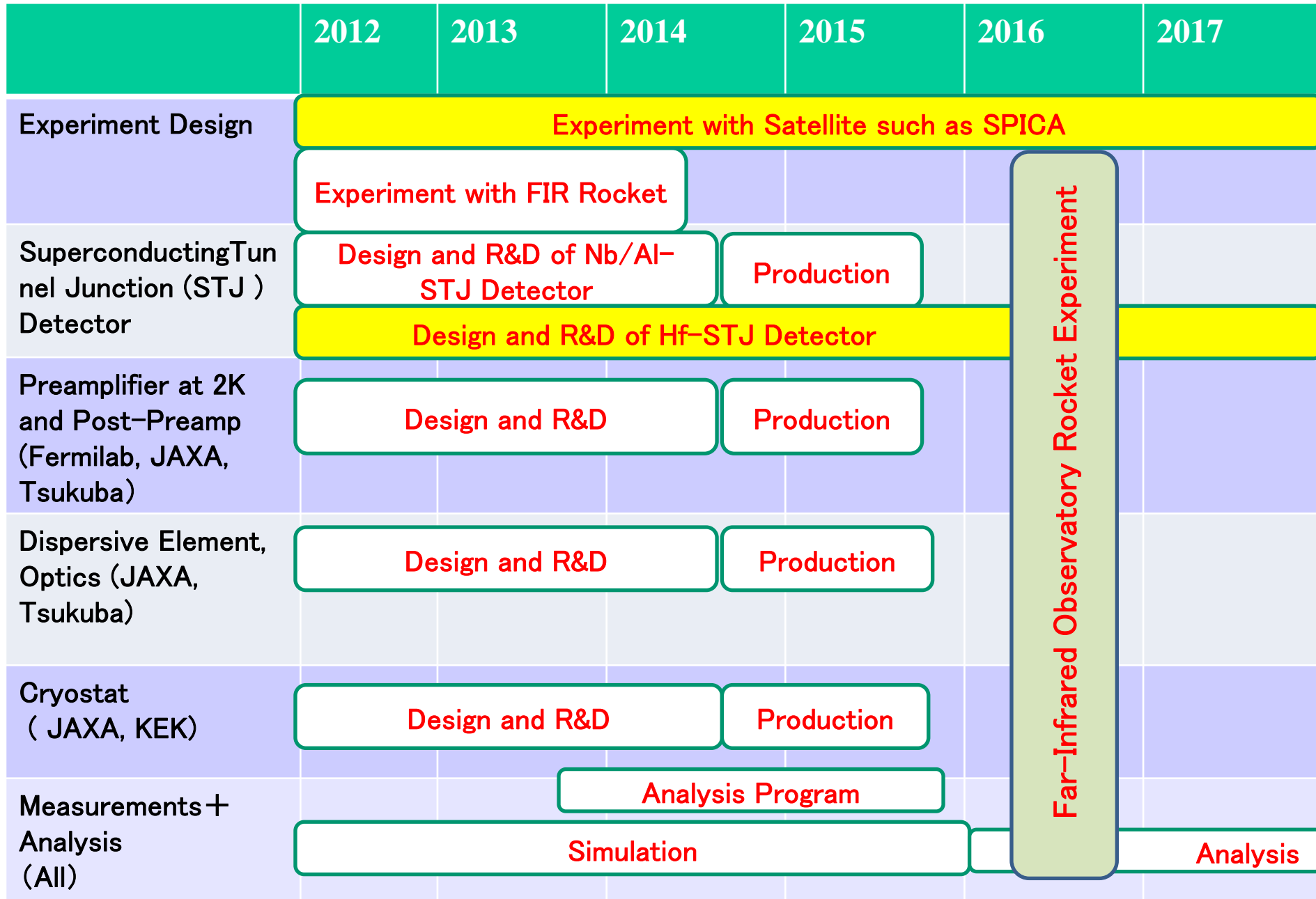
We present the development of a Superconducting Tunnel Junction (STJ) detector using Hafnium (Hf) as a photon detector which was designed to search for radiative decay of cosmic background neutrinos. The photon energy spectrum from neutrino radiative decay has a sharp edge at high energy end. To detect this sharp edge, we need a micro-calorimeter of infrared photons with high energy resolution. We have optimized the condition of producing a Hf-STJ detector and observed that a Hf-STJ detector had Josephson currents which disappeared by applying a magnetic field.

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Superconducting tunnel junction (STJ), neutrino decay, Hf-STJ

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# Schedule





# Plan

1. Design and detector R&D of CIB measurement with a FIR-rocket launched in 2016
  - Multi-cell Nb/Al-STJ (Tsukuba, Fukui, Okayama, Kinki)
  - Low-temperature (2K) preamplifier and post-preamplifier (Fermilab, JAXA, Tsukuba)
  - Dispersive element such as grating (Tsukuba, JAXA)
  - Cryostat (1.7K) (JAXA)
2. Superconducting detector R&D for satellite CIB measurement after 2018
  - Multi-cell Hf-STJ development (Tsukuba, Fukui)

# BACKUP



# 平成25年度予算

項目	金額(千円)
赤外線信号処理システム (ADC+PC)	4,000
読みだし増幅器開発	3,000
冷凍機改良・設計	2,500
冷凍機運転(液体ヘリウム等)	500
検出器製作(フォトマスク、プリント基板、AI円 盤材等)	2,000
記録メディア、プリンタ用紙、印刷費	1,000
旅費(成果発表、研究打ち合わせ)、会議費、 論文投稿、別刷	2,500
研究補助(2人×8か月)、研究支援者雇用費	2,500
計	18,000

# 平成25-29年度予算（単位：千円）

項目	25年度	26年度	27年度	28年度	29年度	計
データ収集解析系	4,000	2,000	2,000	2,000	4,000	
増幅器開発・製作	3,000	4,000	4,000	4,000	500	
冷凍機改良・設計・製作	2,500	2,500	2,500	2,500	0	
冷凍機運転	500	500	500	500	500	
検出器・光学系・光源の開発・製作	2,000	3,000	3,000	3,000	0	
プリンタ用紙、印刷費等	1,000	1,000	1,000	1,000	1,000	
旅費（成果発表、研究打ち合わせ）、会議費、論文投稿、別刷	2,500	3,500	3,500	3,500	3,500	
研究補助（2人×8か月）、研究支援者雇用費	2,500	5,500	5,500	5,500	5,500	
計	18,000	22,000	22,000	22,000	15,000	99,000

# Modified Budget Plan in JFY 2012 (April 2012-March 2013)

Cost (x 1,000Yen or x 12.5\$)

<u>Improvement of Refrigerator</u>	<u>300</u>	<u>Japan</u>
<u>Operation of Refrigerator</u>	<u>200</u>	<u>Japan</u>
<u>Cryostat for rocket experiment</u>	<u>300</u>	<u>Japan</u>
<u>Far-Infrared Light Source</u>	<u>500</u>	<u>Japan</u>
<u>Dispersive Element</u>	<u>200</u>	<u>Japan</u>
<u>Superconducting Tunnel Junction Detector Prototype</u>	<u>1,000</u>	<u>Japan</u>
<u>Electronics at very low Temperature 2K</u>	<u>2,300</u>	<u>Fermilab</u>
<u>Expenses at Fermilab (rent-a-car etc)</u>	<u>200</u>	<u>Fermilab</u>

総計

5,000

- 1,500kYen was sent to Fermilab at the end of May.
- 1,000kYen will be sent to Fermilab at the end of October.

# US Collaborators' Facility at Fermilab

- March, 2011-

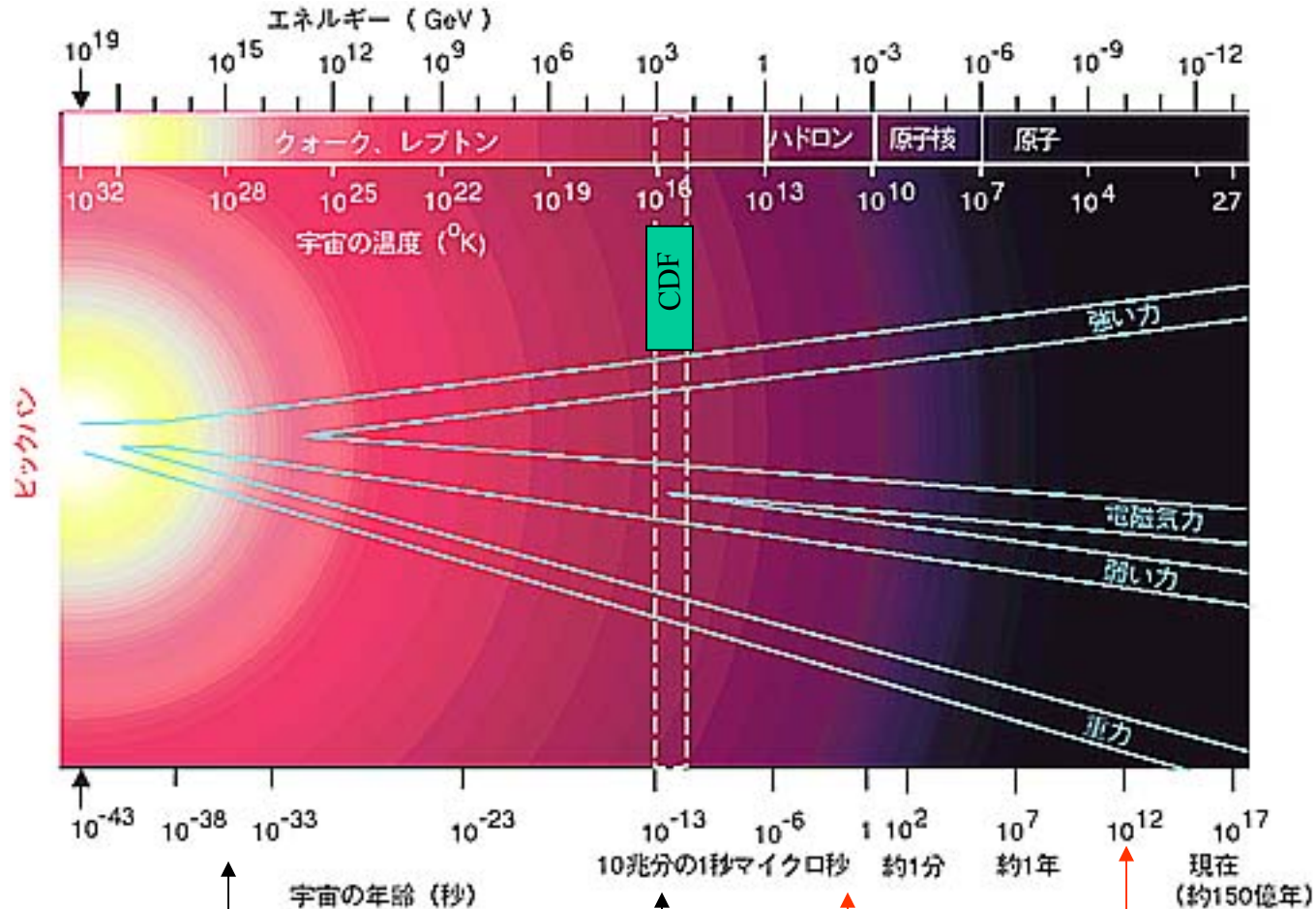
Started a collaboration with Fermilab Milli-Kelvin Facility group who will work on the readout electronics at low temperature around 4K.

## Fermilab Milli-Kelvin Facility

Gustavo Cancelo, Herman Cease, Juan Estrada, Jonghee Yoo, Jiangnag Hao, Josh Frieman  
*Fermi National Accelerator Laboratory, Batavia, IL, 60510, USA*

We propose to build a milli-Kelvin user facility at Fermilab. This facility would provide easy access to a sub-Kelvin cryogenic apparatus for the Fermilab Users. The facility will have immediate uses for SuperCDMS detector R&D, microwave kinetic inductance detector R&D (MKID), and crystal-phase low background detector R&D. Moreover, the facility would attract Users who wish to test devices such as ultra-sensitive superconducting sensors and low-noise quantum devices. An investment in a cryogen-free dilution refrigerator and related test equipment would be instrumental for future detectors and scientific experiments. In this proposal we request engineering/technical hours and support for the facility design and purchase of a cryogen-free dilution refrigerator which requires a year of lead time for delivery.

# Big-Bang Cosmology and Elementary Particle Physics



**GUT**

**Phase Transition in vacuum  
CP violation**

**Electroweak  
Higgs particle**

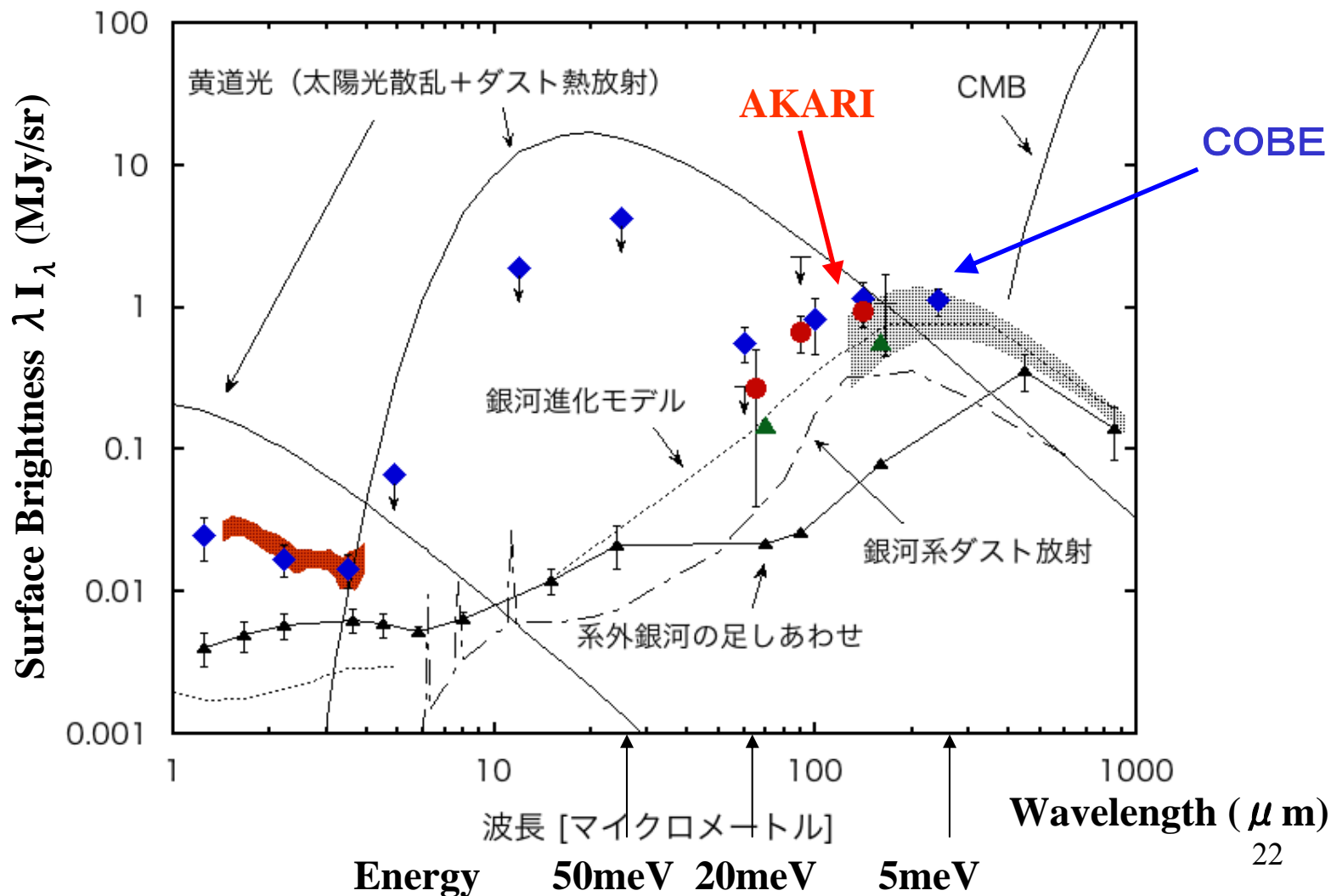
**2.7K Cosmic background radiation  
( $420/\text{cm}^3$ )**

**1.9K Cosmic background neutrino  
( $110/\text{cm}^3$ )**

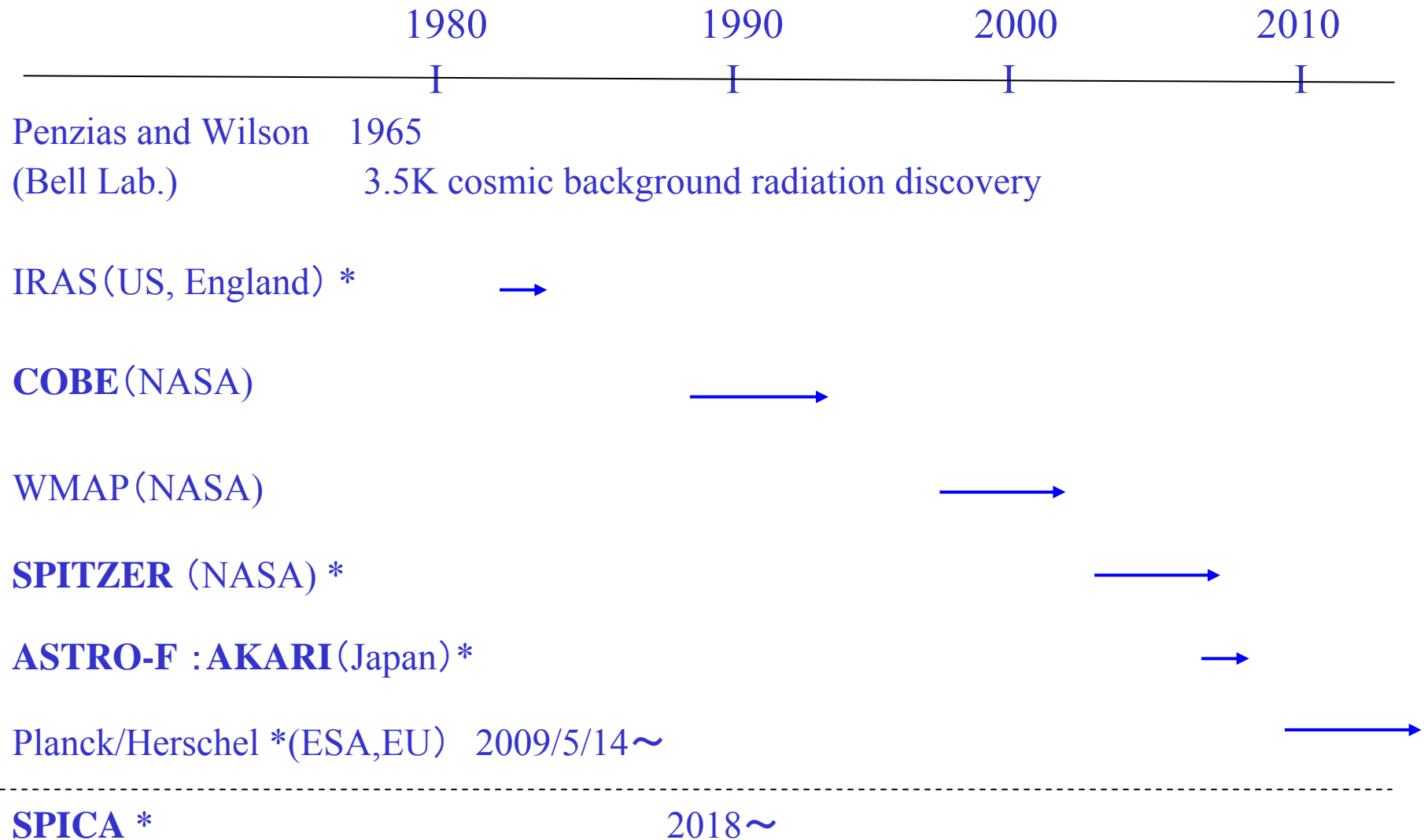
# Cosmic Infrared Background measured by COBE and AKARI

COBE: M. G. Hauser *et al.* *Astrophys. J.* 508 (1998) 25.  
D. P. Finkbeiner *et al.* *Astrophys. J.* 544 (2000) 81.

AKARI: S. Matsuura *et al.* *Astrophys. J.* 737 (2011) 2.



# Status and Plan of Cosmic Background Radiation Observation



\* Satellite for Infrared astronomy

# Neutrino Decay Lifetime

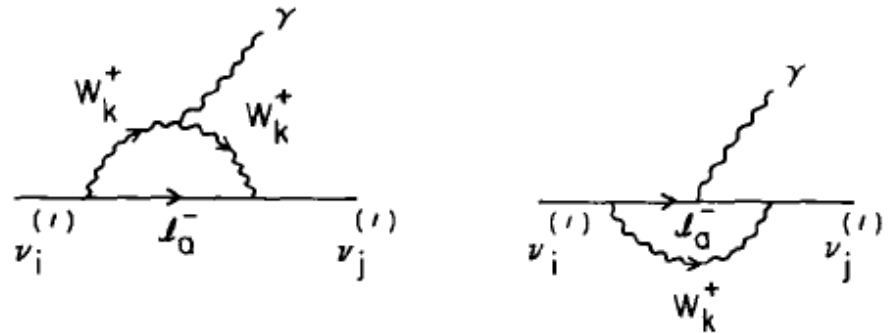
M. Beg, W. Marciano and M. Rudeman Phys. Rev. D17 (1978) 1395-1401  
 R. E. Shrock Nucl. Phys. B206 (1982) 359-379

Calculate the neutrino decay width in  $SU(2)_L \times SU(2)_R \times U(1)$  model  
 $M(W_R) = \infty$  and  $\sin \zeta = 0$  corresponds to Standard Model.

$$W_1 = W_L \cos \zeta - W_R \sin \zeta$$

$$W_2 = W_L \sin \zeta + W_R \cos \zeta$$

$W_L$  and  $W_R$  are fields with pure V-A and V+A couplings, respectively, and  $\zeta$  is a mixing angle.

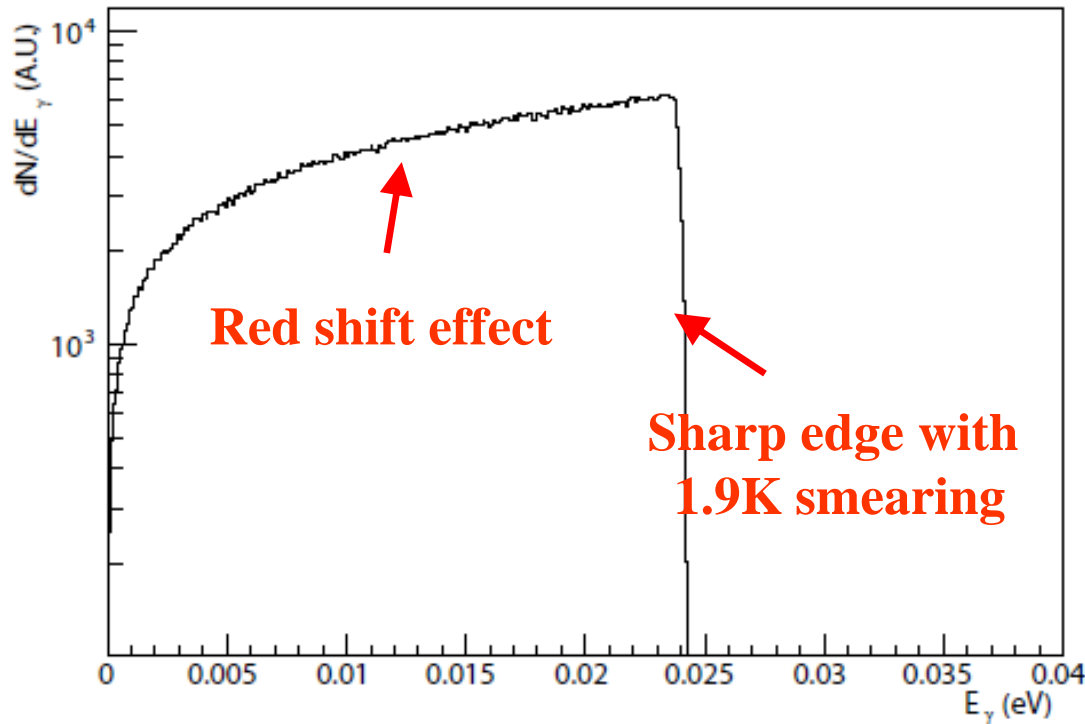


Using a lower mass limit  $M(W_R) > 715 \text{ GeV}/c^2$ , a mixing angle limit  $\zeta < 0.013$ , and  $m_3 = 50 \text{ meV}$ ,

$$\tau(\nu_3 \rightarrow \nu_2 + \gamma) = 1.5 \times 10^{17} \text{ year} \quad (2.1 \times 10^{43} \text{ year in Standard Model})^{24}$$



# Photon Energy Spectrum from Neutrino Decay



- 1.9K neutrino motion smears the sharp edge of high energy end.
- Measured photon energy  $E_\gamma$  is shifted due to Doppler effect given by  $E_\gamma = E_0 / (1+z)$ , Where  $z$  is a red shift and  $E_0$  is the photon energy without Doppler shift and neutrino motion.

$$\frac{dN}{dE_\gamma dS d\Omega dt} = \frac{\rho c}{4\pi\tau H_0 E_\gamma} \left[ \left( \frac{E_0}{E_\gamma} \right)^3 \Omega_M + \Omega_\Lambda \right]^{-\frac{1}{2}}$$

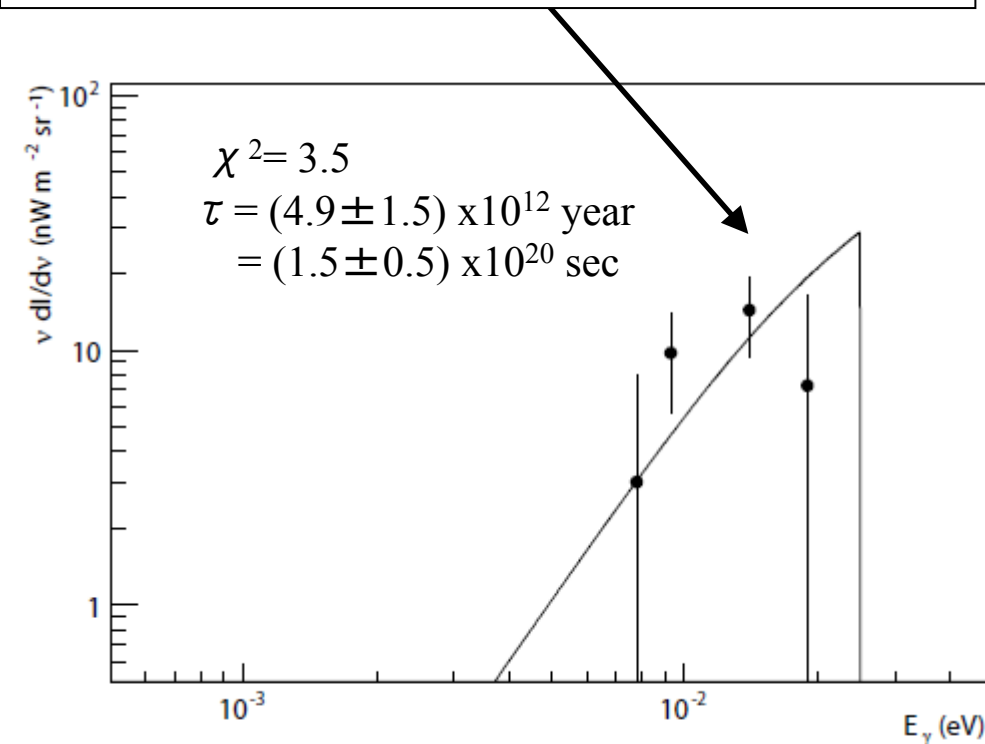
$E_{\gamma rest}$  : photon energy in  $\nu_3$  rest frame,  $\rho$  :  $\nu_3$  density,  $\tau$  :  $\nu_3$  lifetime,

$H_0$  : Hubble constant,  $\Omega_M$  : Matter density(0.76),  $\Omega_\Lambda$  : cosmological constant(0.24)

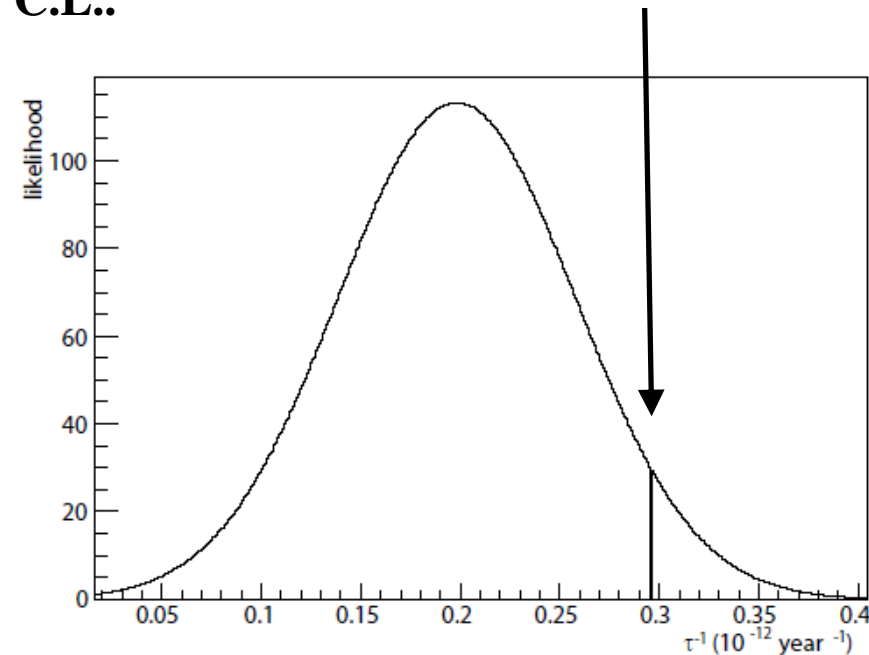
# Our Estimate of Neutrino Lifetime Limit using the Cosmic Infrared Background measured by AKARI

**SPITZER** and **AKARI** measured the contribution of distant galaxies to the CIB. We obtained the neutrino lifetime limit from the AKARI CIB data (ApJ,737, 2, 2011) from which we subtracted the contribution of distant galaxies

**AKARI CIB Data — Contribution of Distant Galaxies**



**Lifetime Limit  $3.4 \times 10^{12}$  year at 95% C.L..**



**Lower limit of neutrino lifetime is  $3.4 \times 10^{12}$  at 95% C.L. for  $m_3 = 0.05 \text{ eV}$  and  $m_2 = 0.01 \text{ eV}$ .  
 For  $m_3 = 0.05 \sim 0.15 \text{ eV}$ , lower limit of  $\nu_3$  lifetime at 95% C.L ranges  $(3.1 \sim 3.8) \times 10^{12} \text{ year}$ .**

# Lifetime Calculation

R. E. Schrock, Nucl. Phys. 28 (1982) 359.

Calculate the neutrino decay width in  $SU(2)_L \times SU(2)_R \times U(1)$  model

$$\tau^{-1} = \frac{\alpha G_F^2}{128\pi^4} \left( \frac{m_3^2 - m_2^2}{m_3} \right)^3 \times |U_{32}|^2 |U_{33}|^2 \left[ \frac{9}{64} (m_3^2 + m_2^2) \frac{m_\tau^4}{M_{W1}^4} \left( 1 + \frac{M_{W1}^2}{M_{W2}^2} \right)^2 + 4m_\tau^2 \left( 1 - \frac{M_{W1}^2}{M_{W2}^2} \right)^2 \sin^2 2\zeta \right],$$

where  $\alpha$  is a fine structure constant,  $G_F$  is a Fermi coupling constant,  $m_\tau$ ,  $M_{W1}$  and  $M_{W2}$  are masses of  $\tau$ ,  $W_1$  and  $W_2$ , respectively.<sup>21,22)</sup>  $U_{ij}$  is the (i, j)-th element of the Maki-Nakagawa-Sakata mixing matrix<sup>23)</sup> and we took  $|U_{32}| = 1/\sqrt{2}$  and  $|U_{33}| = 1/\sqrt{2}$ .

$$\tau^{-1} \approx \frac{\alpha G_F^2}{64\pi^4} \left( \frac{\Delta m_{32}^2}{m_3} \right)^3 m_\tau^2 \sin^2 2\zeta$$

$$M_{W2} = 0.715 \text{ TeV}, \sin\zeta = 0.013, \Delta m_{32}^2 = 2.43 \times 10^{-3} \text{ eV}^2, m_\tau = 1.78 \text{ GeV}, m_3 = 50 \text{ meV},$$

$$\tau = 1.5 \times 10^{17} \text{ year}$$

In the standard model,

$$\tau^{-1} \approx \frac{9\alpha G_F^2}{8192\pi^4} \left( \frac{\Delta m_{32}^2}{m_3} \right)^3 (m_3^2 + m_2^2) \left( \frac{m_\tau^2}{M_W^2} \right)^2 \quad \text{Thus } \tau = 2.1 \times 10^{43} \text{ year}$$

ref. K. Sato and M. Kobayashi, Prog. Theor. Phys. 58 (1977) 1775. and others.

# Lower Limit of Neutrino Lifetime using Cosmic Infrared and Microwave Background measured by COBE

A. Mirizzi, D. Montanino and P. Serpico, “Revisiting cosmological bounds on radiative neutrino lifetime” PRD76, 053007 (2007)

Neutrino Decay Photon Energy Spectrum  $\phi_E$ .

$$\phi_E = \frac{\Gamma_H^\gamma}{4\pi} \frac{n_H}{H(z_H)} + \frac{\Gamma_L^\gamma}{4\pi} \frac{n_L}{H(z_L)},$$

(assuming, for simplicity, a flat cosmology)  $H(z) = H_0 \sqrt{\Omega_M(1+z)^3 + \Omega_\Lambda}$ ,  $H_0 \simeq 73 \text{ km s}^{-1} \text{ Mpc}^{-1}$ , which is the present Hubble expansion rate, and  $\Omega_M \simeq 0.26$  and  $\Omega_\Lambda \simeq 0.74$  are, respectively, the matter and the cosmologi-

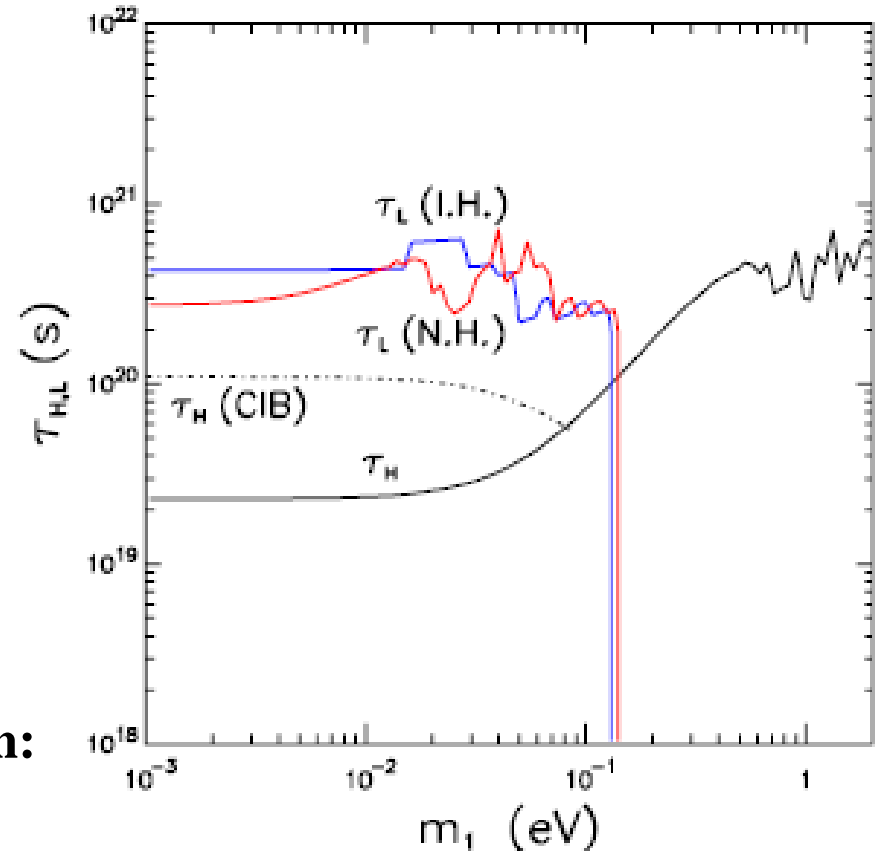
**CMB (Cosmic Microwave Background) :**  
**CMB measured with COBE-FIRAS**  
**CMB is fitted with a sum of 2.7K Plunck distribution and  $\phi_E$ .**

**CIB (Cosmic Infrared Background) :**

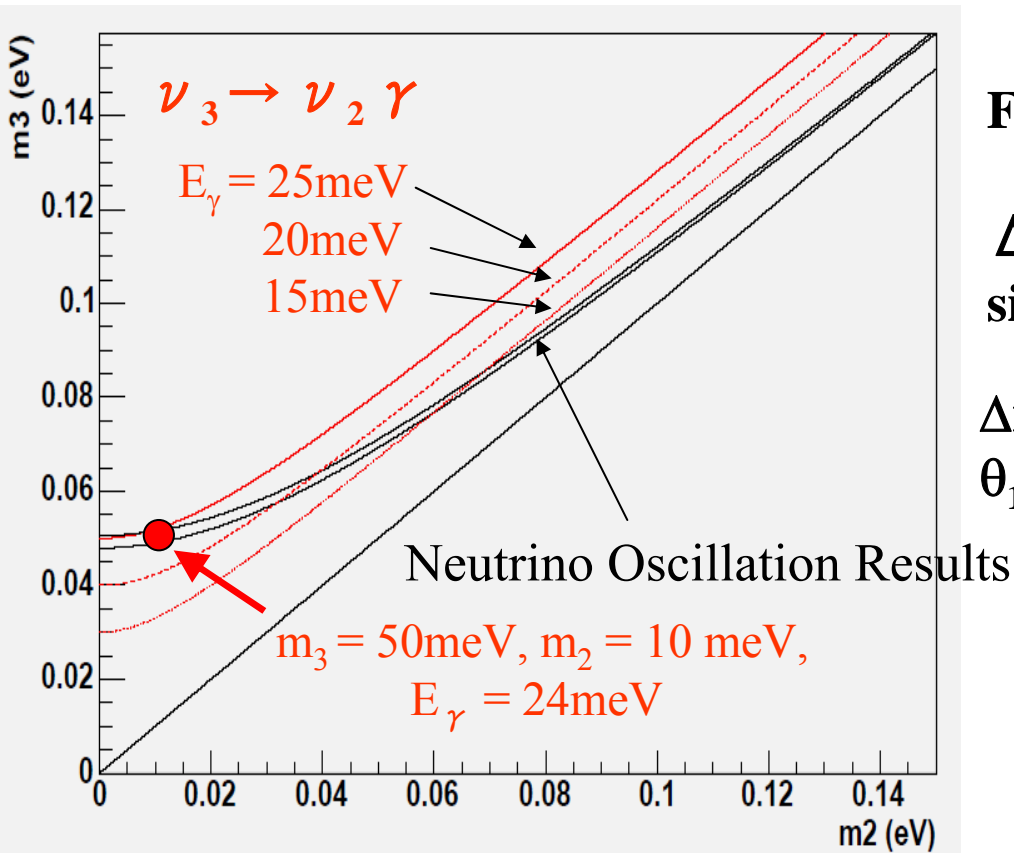
**Calculate  $\tau_H$  by the following equation:**

$$\int_{E_{\min}}^{E_H} \phi_E dE < \Phi_{\text{CIB}},$$

where  $\phi_{\text{CIB}} = 24 \text{ nW m}^{-2} \text{ sr}^{-1}$  (COBE).  $\rightarrow (0.5 \sim 1) \times 10^{20} \text{ sec} = (1.6 \sim 3.1) \times 10^{12} \text{ year}$



# Neutrino Mass Relation



From neutrino oscillation measurement,

$$\Delta m_{23}^2 = (2.43 \pm 0.13) \times 10^{-3} \text{ eV}^2$$

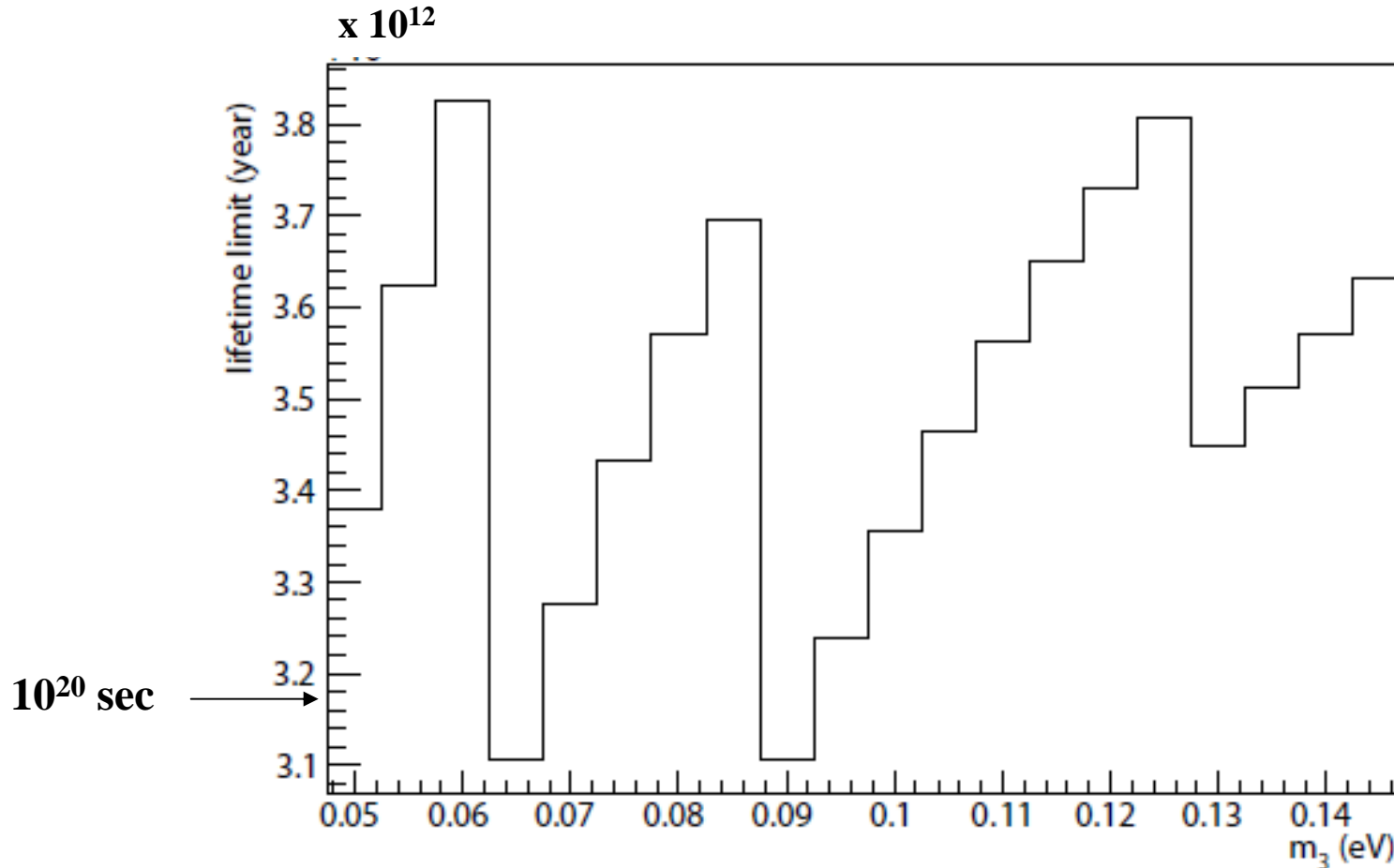
$$\sin^2(2\theta_{23}) > 0.93$$

$$\Delta m_{12}^2 = (7.59 + 0.19 / -0.21) \times 10^{-5} \text{ eV}^2$$

$$\theta_{12} = 34.4 + 1.3 / -1.2 \text{ degrees}$$

\* From Tritium  $\beta$  decay measurement,  $m(\nu_e) < 2 \text{ eV}$

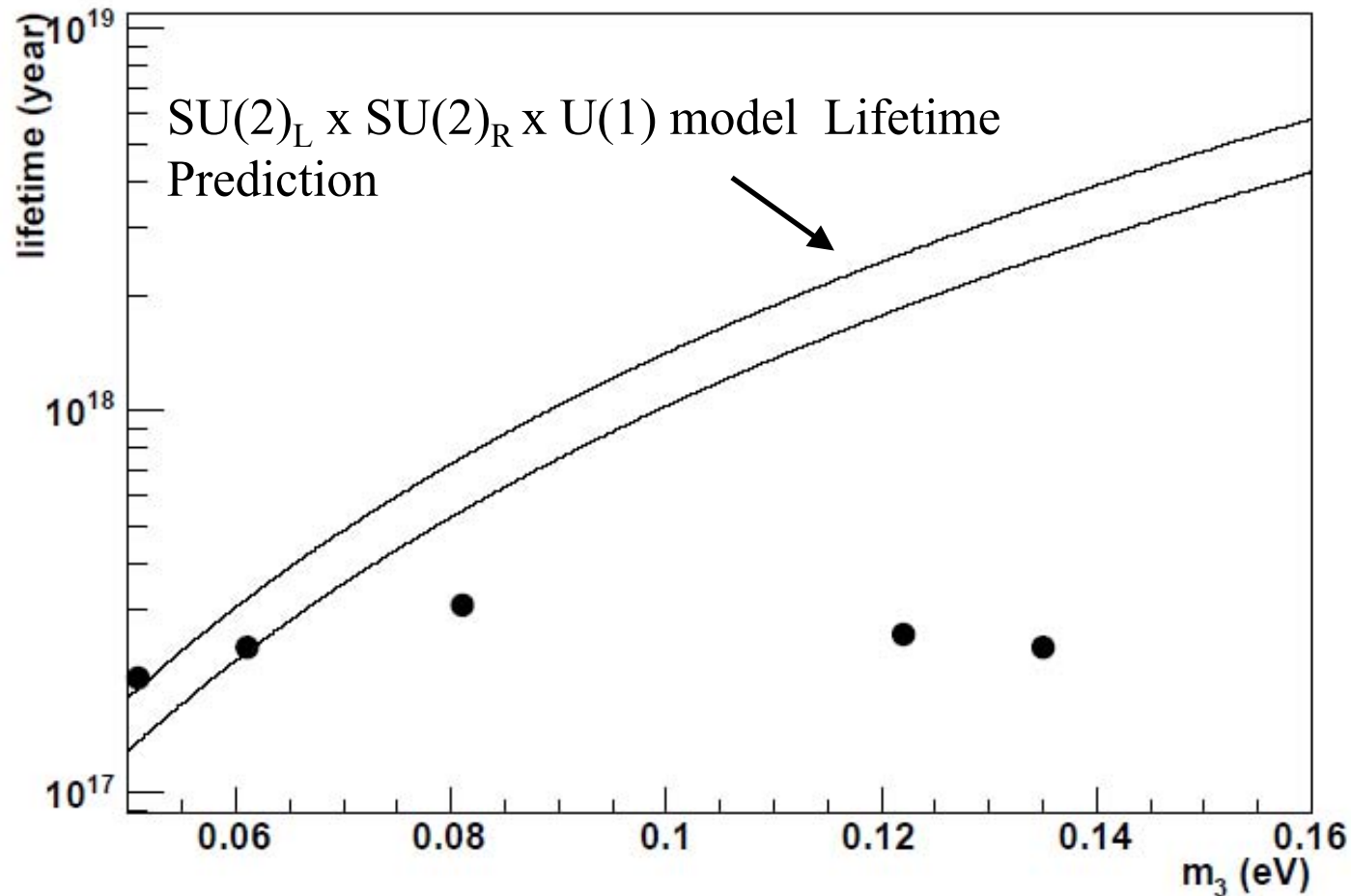
# Our Estimate of Neutrino Lifetime Limit using the Cosmic Infrared Background measured by AKARI (2)



For  $m_3 = 0.05 \sim 0.15 \text{ eV}$ , lower limit of  $\nu_3$  lifetime at 95% C.L ranges  $(3.1 \sim 3.8) \times 10^{12}$  year or  $(1.0 \sim 1.2) \times 10^{20}$  sec.

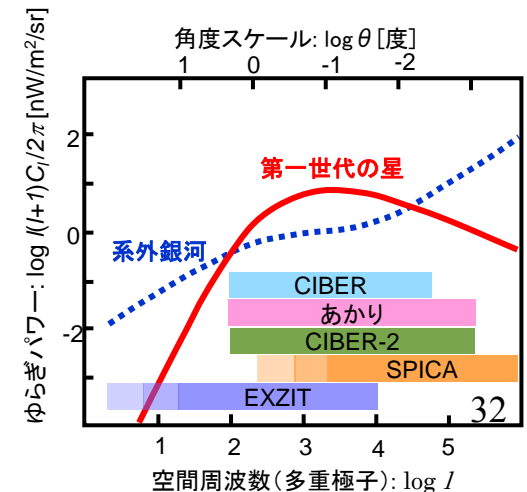
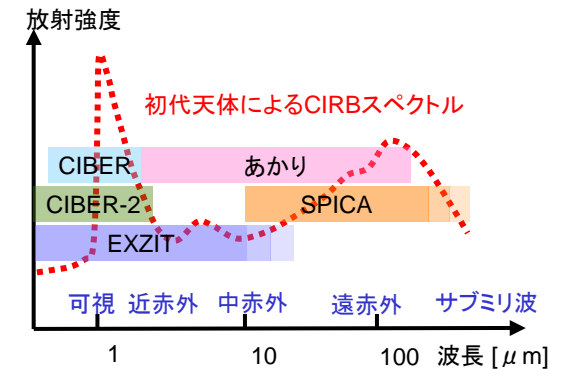
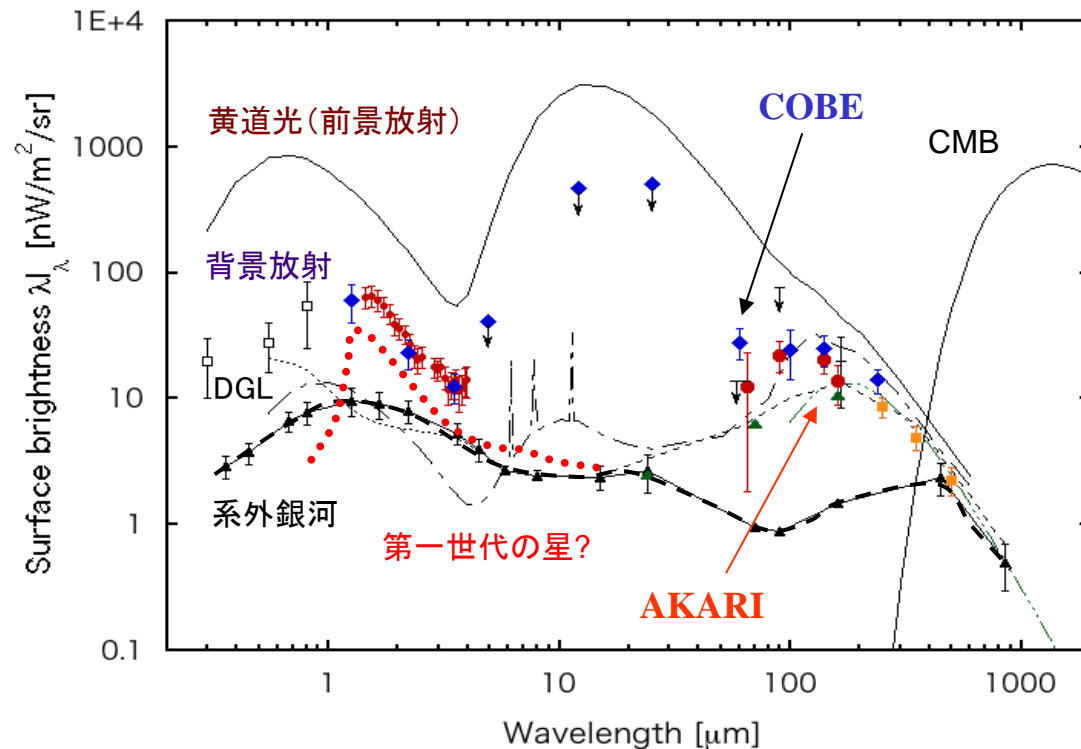
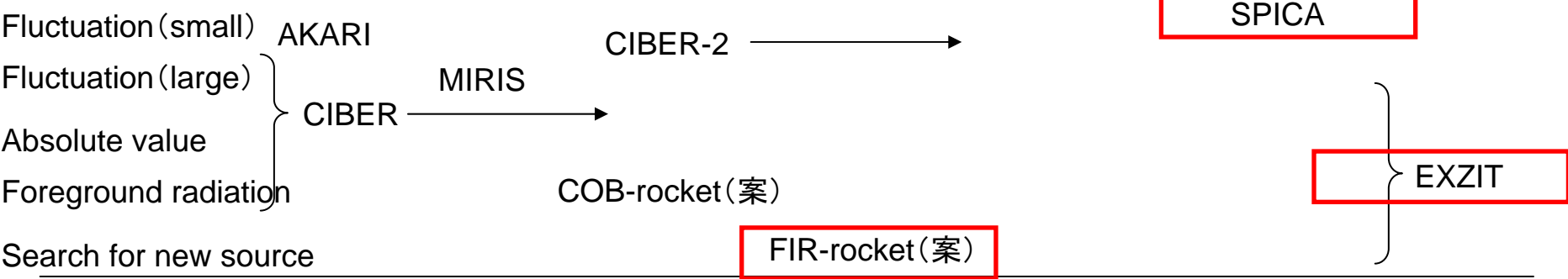
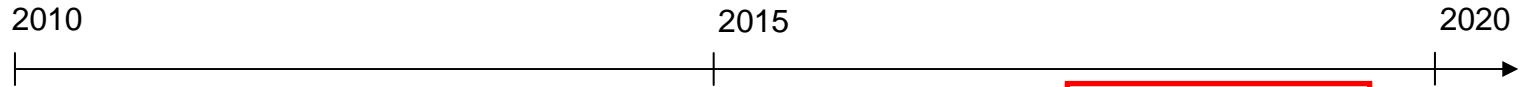
$$\Delta m_{23}^2 = 0.00243 \text{ eV}^2$$

## Neutrino Decay Detection Sensitivity (2)



●  $5\sigma$  observation sensitivity by 10-hour measurement with a telescope with 20 cm diameter, a viewing angle of 0.1 degree and 100% detection efficiency. 31

# CIB Observation Plan ( by JAXA Dr. Matsuura)





# Experiment Plan

**Search for cosmic background neutrino decay with far-infrared observatory rocket launched in 2015**

- **Experiment Design**
- **Development of Multi-channel Nb/Al Superconducting Tunnel Junction (STJ) Infrared Photon Detector**
- **Development of Preamplifier and Shaper operating at 4K**
- **Design and Production of Dispersive Element and Optical System**
- **Design and Production of Cryostat**

**Search for cosmic background neutrino decay with far-infrared observatory satellite such as SPICA launched after 2018**

- **Experiment Design**
- **Development of Hf Superconducting Tunnel Junction (STJ) Infrared Photon Detector**

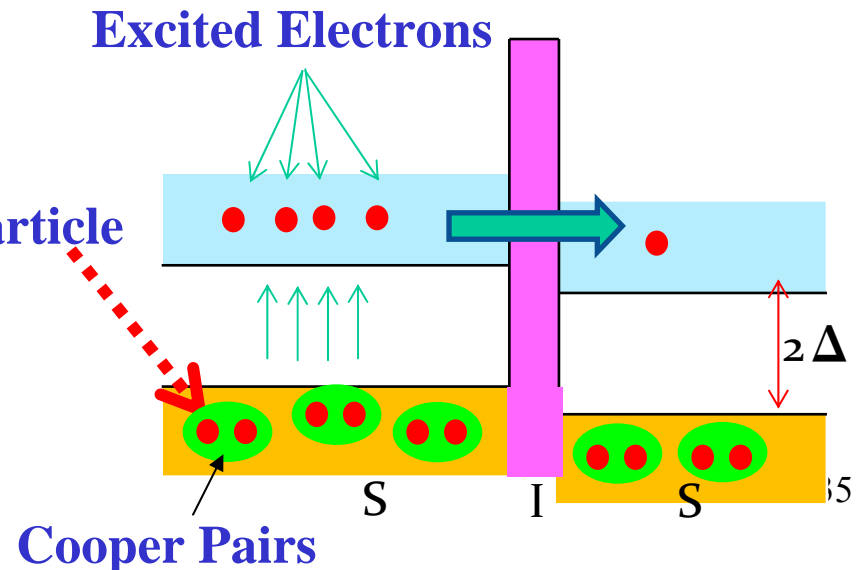
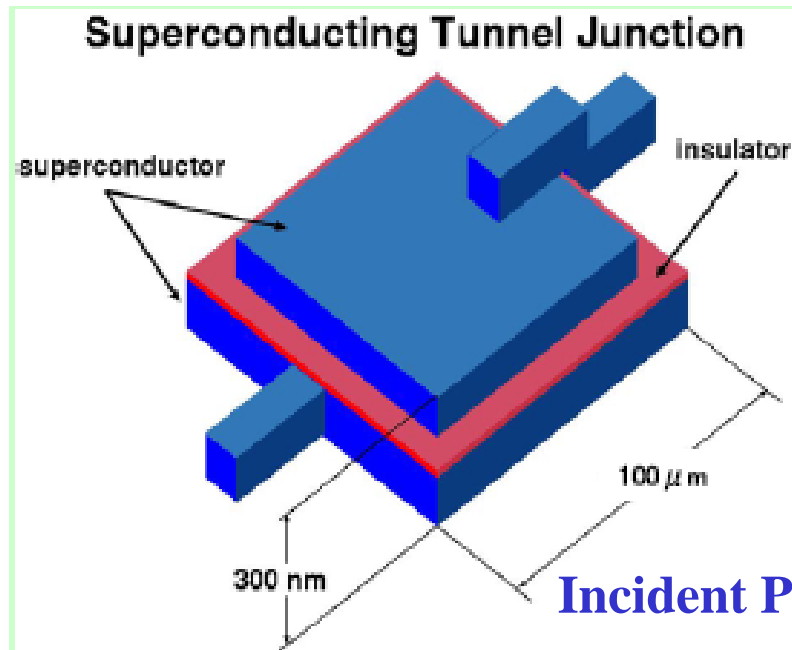
# **Superconducting Tunnel Junction (STJ) Detector**

# STJ (Superconducting Tunnel Junction) Detector

- Superconductor / Insulator / Superconductor Josephson Junction

At the superconducting junction, excited electrons (quasi-particles) over their energy gap go through tunnel barrier by a tunnel effect.

By measuring the tunnel current of electrons excited by an incident particle, we measure the energy of the particle.



# STJ Energy Resolution

## STJ Energy Resolution

$$\sigma_E = \sqrt{1.7\Delta(FE)}$$

Using Hf as a superconductor,

$$\sigma_E / E = 1.7\% \quad \text{at } E = 25\text{meV}$$

$\Delta$ : Band gap energy

F: Fano factor (= 0.2)

E: Incident particle energy

Material	$T_c(K)$	$\Delta(\text{meV})$
Niobium	9.20	1.550
Aluminum	1.14	0.172
Hafnium	0.13	0.021

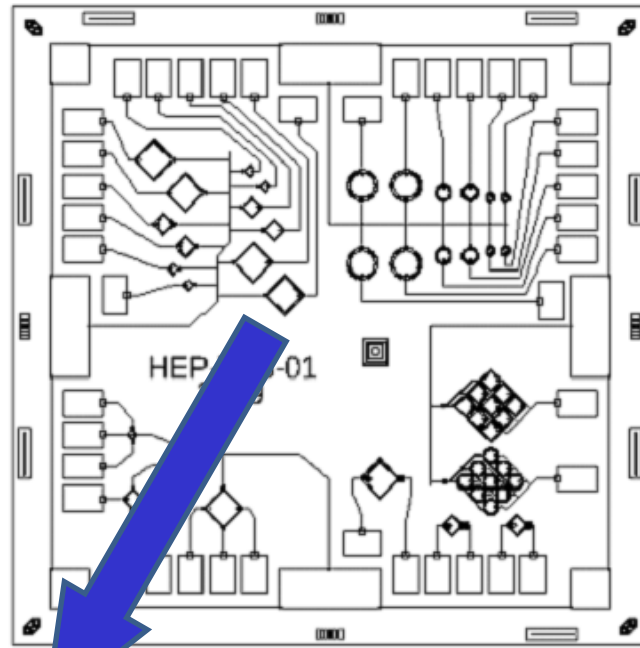
## Tc : Critical Temperature

Operation is done at a temperature around 1/10 of Tc

No paper on Hf-STJ test in the world.

# Hf-STJ Structure

Mask Design



5mm

50, 100, 200  $\mu\text{m}$

Enlarging

Cross Section

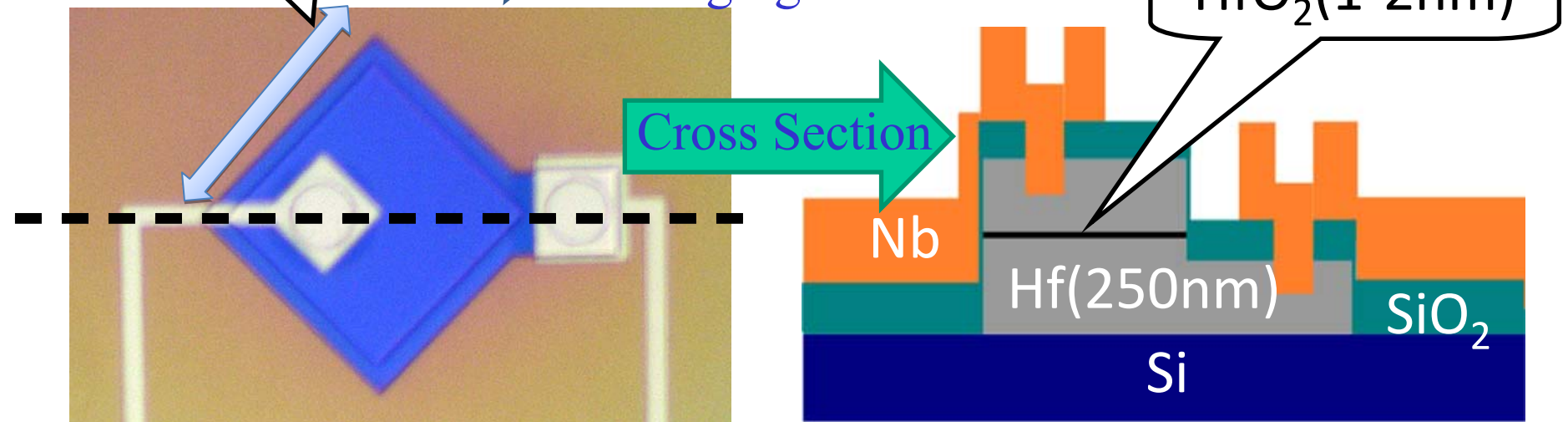
HfO<sub>2</sub>(1-2nm)

Nb

Hf(250nm)

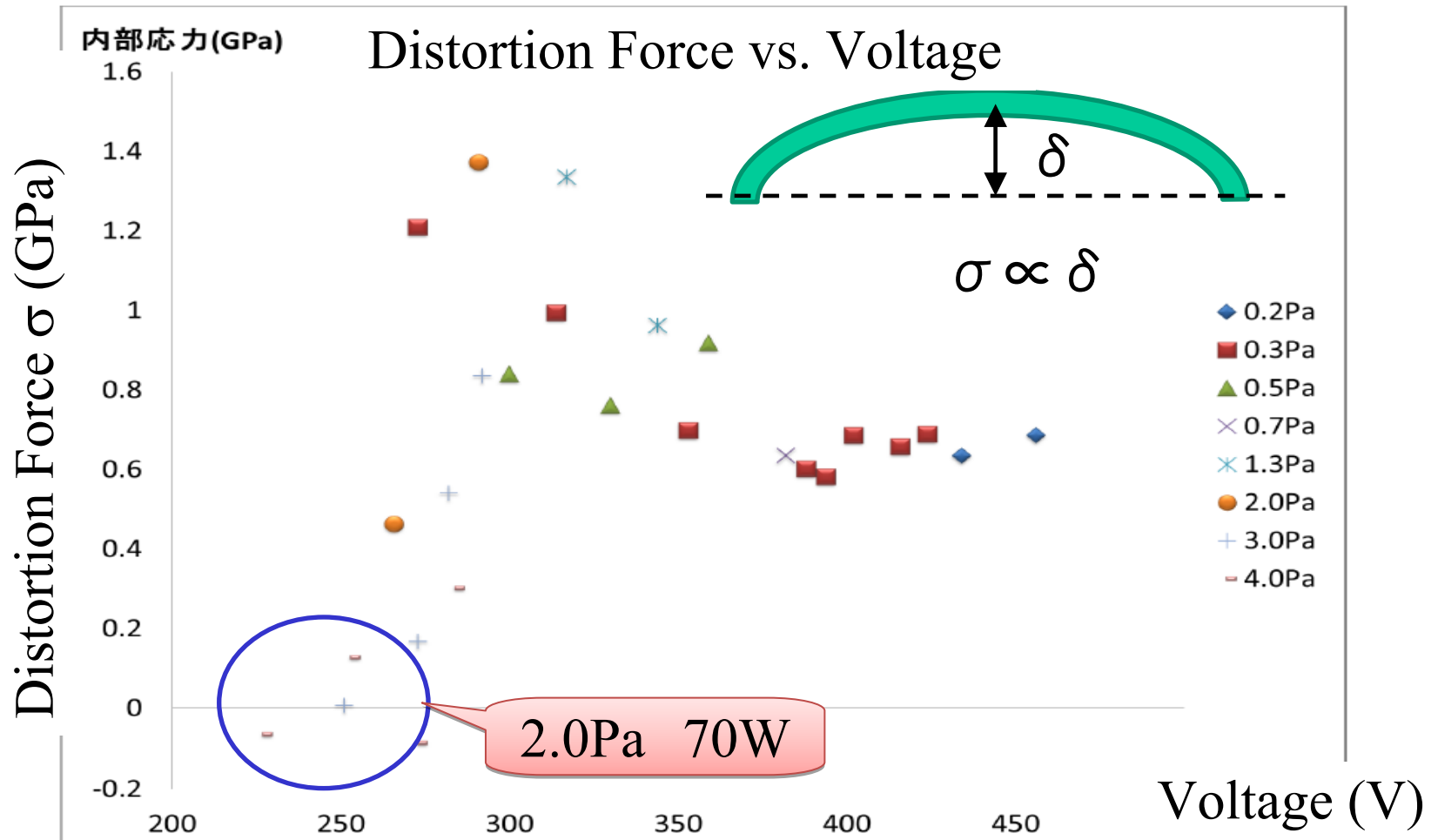
SiO<sub>2</sub>

Si



# R&D Status

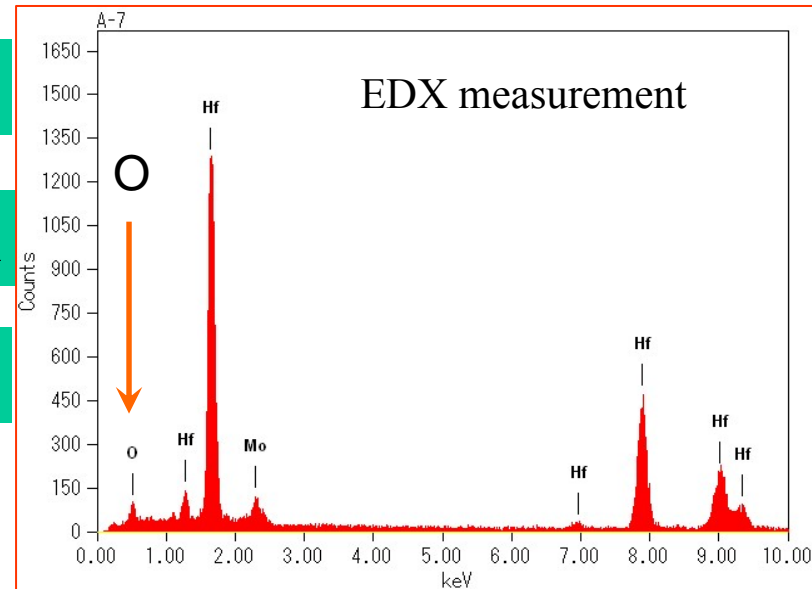
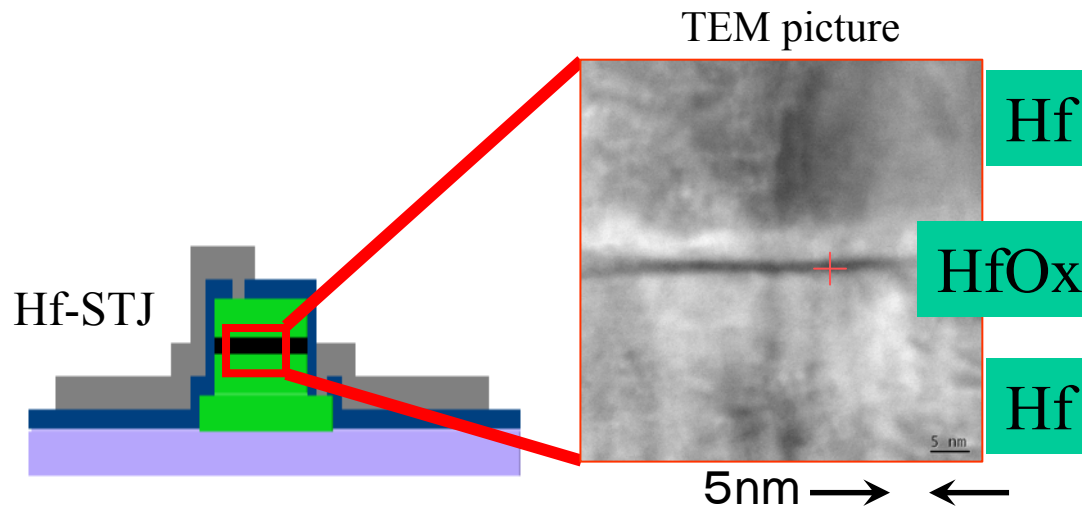
- (1) Search for the best condition for making a flat Hf layer :  
various pressures and voltages.
- 2.0 Pa, 70W (optimized)



# R&D Status

(2) Search for the best condition for making the insulator layer (1 – 2 nm thick ) as a tunnel barrier: various pressures and periods of oxidation.

- 5 Torr, 12 minutes Oxidation sample (TEM picture )
  - **Confirmed 1.3nm-thick  $\text{HfO}_2$  layer**

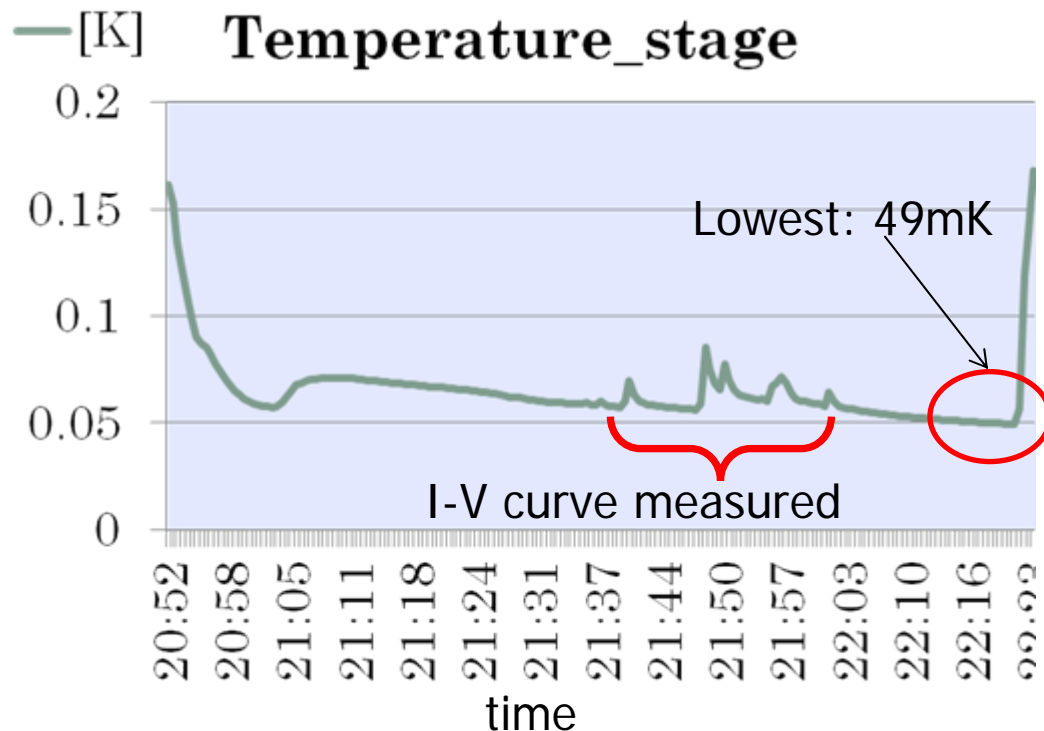


- TEM: Transmission Electron Microscope
- EDX: Energy Dispersive X-ray Spectroscopy

# R&D Status

## (3) Operation of He<sub>3</sub>/He<sub>4</sub> Dilution Refrigerator.

- We borrowed a He<sub>3</sub>/He<sub>4</sub> Dilution Refrigerator from a group of Low Temperature Material Science at University of Tsukuba in 2008.
- Achieved 49mK in July 2009.
- Achieved 40mK in October 2011.





# Specification of 4K preamplifier

- Erik,

Mail from me to Erik on Dec. 18, 2011

- I am sending the specifications about 4K electronics.

If you have a mK facility at Fermilab, we can test the 4K electronics together with a Hf Superconducting detector. However even if you do not have the mK facility, when you can develop and test 4K electronics, your contribution is very useful for this experiment. About the test of Nb/Al-STJ, 0.4K is enough for the test of preamplifier with the Nb/Al-STJ.

**Our plan is to look at signals from visible photon ( $\lambda=410\text{nm}$ ) and near-infrared photon ( $\lambda=1\mu\text{m}$ ) using a laser in 2012.** For this purpose, we need a prototype preamplifier as specified below.

**In 2013, we plan to look at signals from far-infrared photon ( $\lambda=30\mu\text{m}$ ) and make a prototype of multi-channel preamplifiers for Nb/Al-STJ (400 channels).**

Requirement for preamplifiers of Nb/Al-STJ and Hf-STJ is summarized below:

- Common specification: Operation temperature:  $\sim 4\text{K}$  Integration time: 10  $\mu\text{sec}$

## <For the Nb/Al-STJ and Hf-STJ prototype design>

Dynamic range  $< 20\text{fC}$  ( $\sim 1.2 \times 10^5 \text{ e}$ )

from the requirement of  $< 4.5\text{eV}$  gamma ( $\lambda=270 \text{ nm}$ ) at HF-STJ

Noise  $< 0.34 \text{ fC}$  ( $\sim 2100 \text{ e}$ )

from the requirement of  $< 2.5\%$  for  $13.4 \text{ fC} = 3 \text{ eV}$  gamma ( $\lambda \sim 410 \text{ nm}$ ) at Hf-STJ

and of  $< 20\%$  for  $1.6\text{fC} = 3 \text{ eV}$  gamma ( $\lambda \sim 410 \text{ nm}$ ) at Nb/Al-STJ

Gain:  $400\text{mV/fC}$

## <For Nb/Al-STJ final design>

Dynamic range  $< 0.16\text{fC}$  ( $\sim 1000 \text{ e}$ )

from the requirement of  $< 300 \text{ meV}$  gamma at Nb/Al-STJ

Noise  $< 0.0045\text{fC}$  ( $\sim 30\text{e}$ )

from the requirement of  $< 35\%$  for  $0.013 \text{ fC} = 25\text{meV}$  gamma at Nb/Al-STJ

Gain:  $10\text{V/fC}$

## <For Hf-STJ final design>

Dynamic range  $< 4.3\text{fC}$  ( $\sim 27000 \text{ e}$ )

from the requirement of  $< 45\text{meV}$  gamma at HF/W-STJ

Noise  $< 0.012\text{fC}$  ( $\sim 80\text{e}$ )

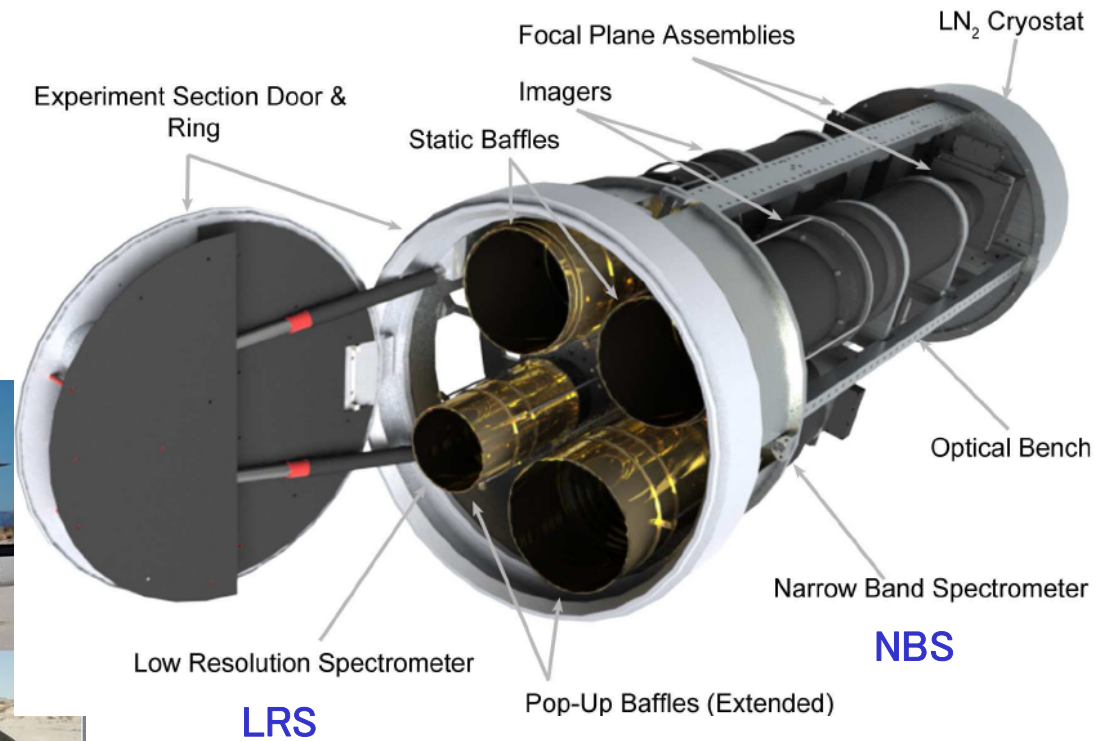
from the requirement of  $< 0.5\%$  for  $2.4 \text{ fC} = 25\text{meV}$  gamma at Hf/W-STJ

Gain:  $1\text{V/fC}$

Best regards,  
Shinhong

# CIBER ロケット実験

CIBERロケット実験の第1回打上  
げの瞬間(2009年2月25日)

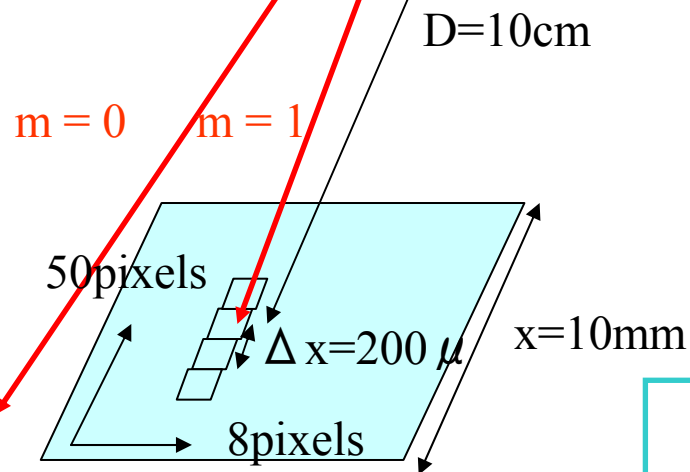
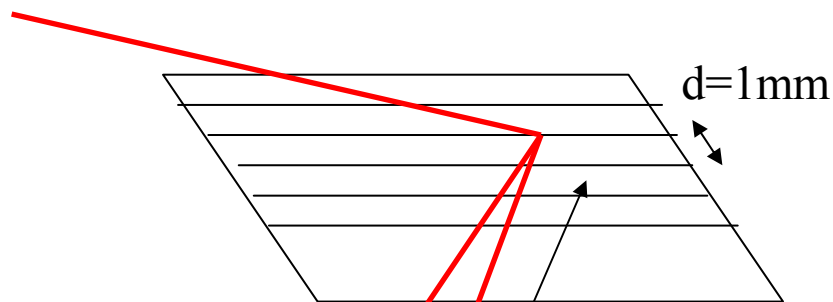


CIBER搭載装置(撮像装置Imager×2、  
低分散分光器LRS、高分散分光器NBS)

# CIB Experiment for Neutrino Decay Search with JAXA Rocket

20minutes DAQ at 200km height in 2015

Grating



$$d \sin \theta = \lambda$$

$$\rightarrow x = D \theta = D \lambda / d = 100 \lambda$$

If  $\Delta x = 200 \mu$ ,  $\Delta \lambda = 2 \mu$

Focal plane Instruments

Grating

Tertiary mirror

Superconducting Tunnel Junction (STJ) Detector Array (50 x 8 channels)

IR Light

Secondary mirror

Main Mirror  
15cm  $\phi$   
F=1m

Focal plane Instruments

LHe Cryostat  
1.6K

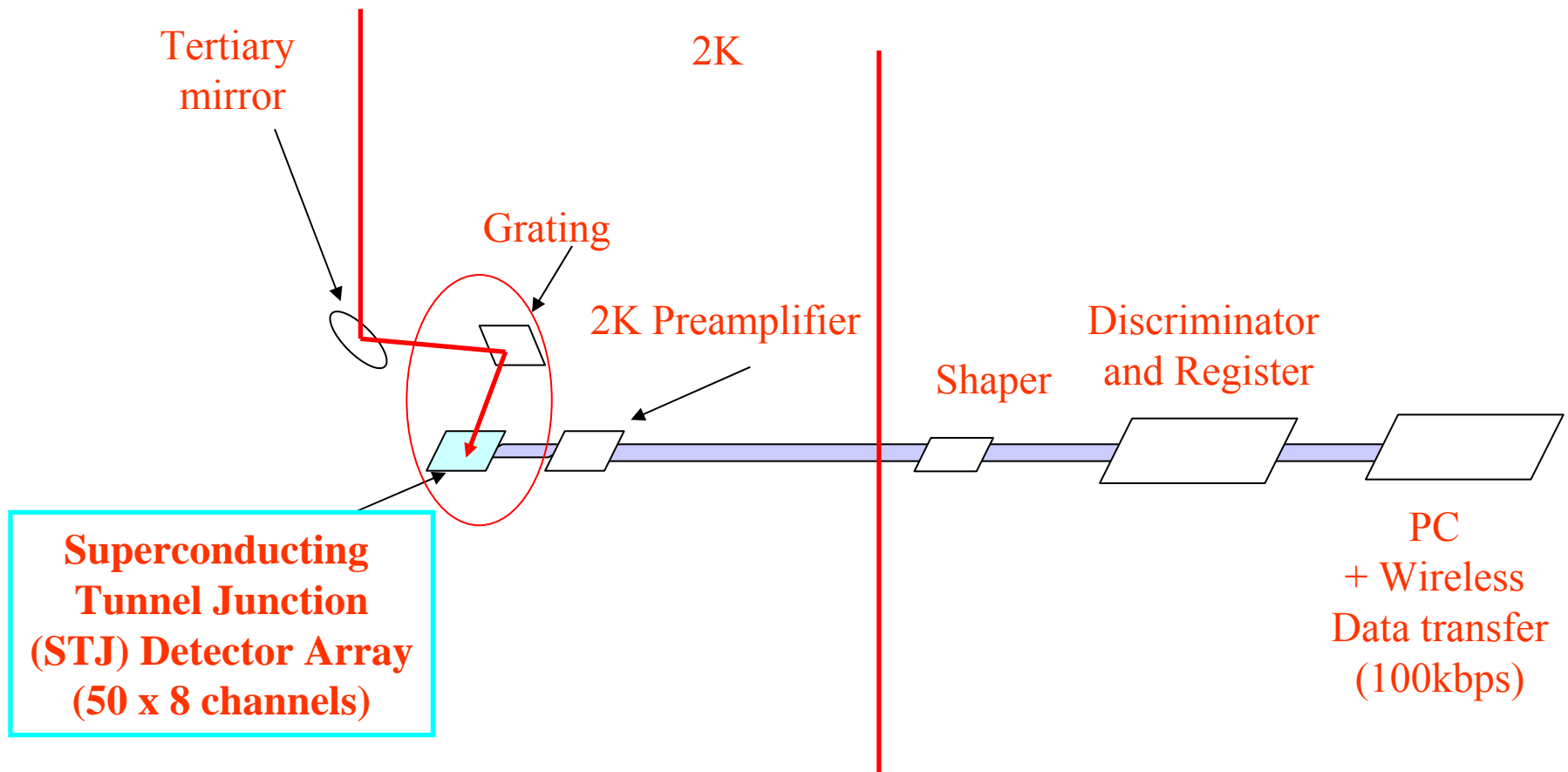
43

Readout Electronics(4K)

# Readout Electronics ( Post- Preamplifier )

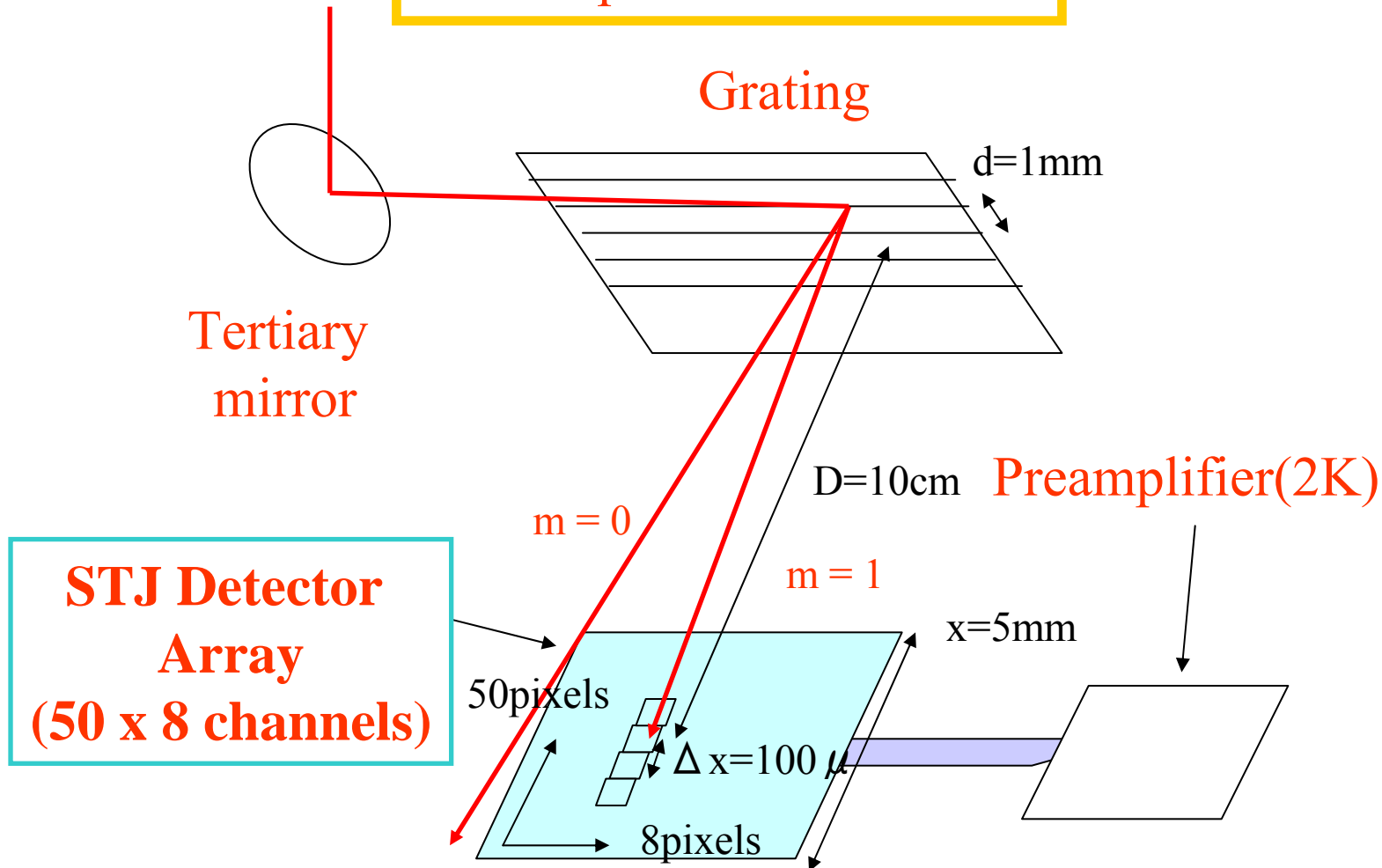
Focal plane Instruments

Post-preamplifier



# CIB Experiment for Neutrino Decay Search with JAXA Rocket Focal Plane Instruments

## Focal plane Instruments



# CIB Experiment for Neutrino Decay Search with JAXA Rocket

## Rate Calculation and Expected Lifetime Limit

Radiation Rate  $\lambda I_\lambda \sim 1 \mu\text{W/m}^2/\text{sr}$  for  $\lambda = 40 \mu\text{m}$

1Pixel  $\Delta\Omega = 10^{-8} \text{ sr}$ ,  $\Delta S = \pi \times 0.075^2 \text{ m}^2$

$\lambda I_\lambda = 1.75 \times 10^{-16} \text{ W} = 1.1 \times 10^3 \text{ eV/s}$  ( Using  $1\text{J} = 6.2 \times 10^{18} \text{ eV}$  )

From  $\lambda I_\lambda = E dI/dE$   $dI/dE = 1.1 \times 10^3 / (3 \times 10^{-2}) \text{ s}^{-1} = 0.35 \times 10^5 \text{ s}^{-1}$

$dI/dE = (E/\Delta E) dN/dt$  より、  $dN/dt = 0.7 \times 10^3 \text{ s}^{-1}$  ( Using  $E/\Delta E = 50$  )

Rate/pixel = 0.7kHz at  $\lambda = 40 \mu\text{m}$

Measurements for 200 s

→ 140 k events /pixel

We use 8 rows of 50pixel-spectrometer. → 1120k events/photon energy

$\sigma/N = 0.094\%$   $2\sigma = 0.19\% \times 1 \mu\text{W/m}^2/\text{sr}$

$= 1.9\text{nW/m}^2/\text{sr}$

(about 6% of the present limit of  $30\text{nW/m}^2/\text{sr}$  )

# Readout Electronics ( 2K Preamplifier )

# Specification of 2K preamplifier

- Common specification: Operation temperature:  $\sim 2\text{K}$   
Integration time:  $10\ \mu\text{sec}$

## <For the Nb/Al-STJ and Hf-STJ prototype design>

Dynamic range  $< 20\text{fC}$  ( $\sim 1.2 \times 10^5\text{ e}$ )

from the requirement of  $< 4.5\text{eV}$   $\gamma$  ( $\lambda = 270\text{ nm}$ ) at Hf-STJ

Noise  $< 0.34\text{ fC}$  ( $\sim 2100\text{ e}$ )

from the requirement of  $< 2.5\%$  for  $13.4\text{ fC} = 3\text{ eV}$   $\gamma$  ( $\lambda = 410\text{ nm}$ ) at Hf-STJ

and of  $< 20\%$  for  $1.6\text{fC} = 3\text{ eV}$   $\gamma$  ( $\lambda = 410\text{ nm}$ ) at Nb/Al-STJ

Gain:  $40\text{mV/fC}$  ( $0.064\text{V}/1.6\text{fC}$ )

## <For Nb/Al-STJ final design>

Dynamic range  $< 0.064\text{fC}$  ( $\sim 400\text{ e}$ )

from the requirement of  $< 300\text{ meV}$   $\gamma$  at Nb/Al-STJ

Noise  $< 0.0026\text{ fC}$  ( $\sim 16\text{ e}$ )

from the requirement of  $< 20\%$  for  $0.013\text{ fC} = 25\text{meV}$   $\gamma$  at Nb/Al-STJ

Gain:  $1\text{V/fC}$  ( $0.013\text{V}/0.013\text{fC}$ )

## <For Hf-STJ final design>

Dynamic range  $< 4.3\text{fC}$  ( $\sim 27000\text{ e}$ )

from the requirement of  $< 45\text{meV}$   $\gamma$  at Hf/W-STJ

Noise  $< 0.012\text{fC}$  ( $\sim 80\text{e}$ )

from the requirement of  $< 0.5\%$  for  $2.4\text{ fC} = 25\text{meV}$   $\gamma$  at Hf/W-STJ

Gain:  $1\text{V/fC}$  ( $2.4\text{V}/2.4\text{fC}$ )